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The New Fibers



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The New Fibers

by

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PREFACE

The textile industry is just beginning to feel the effects of the chemical revolution, which has already brought about far-reaching changes in many other industries. Natural fibers still constitute the great preponderance of textile materials used in our civilization, but the future should witness a steady increase in the use of fibers which are either chemically made or chemically improved.

A number of distinctly new types of fibers have been introduced during the past decade; many others are still in the laboratory or pilot-plant stage. To meet the threat of increased competition, the older fibers are being improved.

This is the first book that tells the story of all these developments. It has been prepared to meet the demand for a book that brings together information on new fibers and filaments—for the textile and other industries which are using or planning to use them; for students and research workers who are endeavoring to enrich the heritage of the past by the development and utilization of newer and better types of materials; and for the general reader who wishes to know how these materials may affect our lives.

The book includes a general discussion of the development of new fibers and a comparison of their properties with those of the older established fibers.

A chapter is devoted to each of the important new fibers or groups of fibers, and it includes a summary of the history and development, manufacture, chemical and physical properties, established and potential applications, and available data on volume of production and prices. The chemistry of each of the important new fibers is discussed and structural formulas are included.

The authors have attempted to make the book as useful as possible by including a classified list of new fibers suggested for various applications. There is also a comprehensive list of trade names and manufacturers. The main emphasis of the book has been placed on what the new fibers can be made to do and how they can be used.

Finally, there is a broad discussion of trends in research and development work for both the manufactured and natural fibers with an appraisal of their competitive positions.

An appendix contains a classified list of patents taken out in the United States within the past 10 years dealing with new or improved fibers. The authors do not claim that this list is complete, but believe that it covers the great majority of basic and important patents.

Although part of the material in this book has appeared previously in one form or another in the literature, a substantial portion has been specially prepared and is presented herewith for the first time.

J. V. S.
S. L. S.

New York, N. Y.
September 1946

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Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 2. This shows the actual transformation of viscose spinning solution into rayon filaments as they come from the spinneret.

CHAPTER I

Introduction

From the dawn of civilization up until near the end of the nineteenth century, man used only the fibers he found in nature for textiles and other purposes.

The use of cotton, wool, silk, flax, and asbestos can be traced back for several thousand years and these fibers are still of great importance. Flax (linen), which is probably the oldest of all textile fibers, was used in Europe as early as the Stone Age. Excavation of ancient graves in Asia and Peru has yielded cotton fabrics. Egyptian tombs have contained asbestos grave cloths. The oldest evidence of wool comes from Asia-Minor, from Tel Asmar, the great hill or mound for which the date is set at 4200 B. C.—6000 years ago! Silk was produced in ancient China.

For thousands of years, man continued to be dependent upon these natural fibers with all their inherent limitations.

The idea of making fibers finally occurred to him. It grew out of the desire to obtain a material similar to the highly prized and expensive silk, which had long been the mark of wealth and prestige. Robert Hooke in 1664 and R. A. F. Reaumur in 1734 suggested that fibers might be spun by methods similar to those employed by silk worms and spiders. Reaumur went so far as to suggest the spinning of natural gums and resins. Nothing was done about it for the next hundred years.

About 1840, Schwabe, a silk manufacturer in Manchester, England, experimented with machines to draw out substances through fine holes into filaments or threads, and in essence suggested the rayon spinneret and spinning machine. Materials then available, such as gelatin, egg albumin, agar agar, and car-

ragheen moss, were tried out, but none of them gave products as satisfactory as mercerized cotton, which was originated by Mercer in 1844.

The search for materials from which to make filaments continued to attract the attention of scientists. Among the many investigators in this field was Count Hilaire de Chardonnet, who had been a pupil of Pasteur at the Ecole Polytechnique in Paris, when the latter's investigations in connection with silk worm diseases were brought to a successful conclusion. It is believed that this was the source of Chardonnet's interest in textile fibers, an interest which resulted in his being the first to develop a successful fiber from nitrocellulose (the first rayon). His exhibit of these new fibers at the Paris Exposition in 1889 caused a sensation in the scientific world, and stimulated the search for other methods of making rayon, which resulted finally in the cuprammonium, viscose and acetate processes.

These processes were first developed in Europe and it was not until 1910 that the first rayon plant, based on the viscose process, was established in America. After a period marked by struggles to overcome technical difficulties and obtain consumer acceptance, the growth of the rayon industry became very rapid. The public acceptance of rayon indicated clearly that a new fiber could be successfully commercialized if it had outstanding characteristics different from those of the previously available fibers.

The growth of rayon has been paralleled by continuous improvement in quality and reduction in price. As a result, it has outpaced wool and silk in importance and is now second only to cotton. However, the consumption of rayon is still little more than 10% of the combined consumption of cotton, wool, silk, and rayon.

The development of rayon represented the first big break from nature in the fiber-producing business. But rayon is a true man-made fiber only in the mechanical sense of the word. Chemically, it is based on cellulose, which is not a man-made, but a natural material. However, cellulose may be modified chemically in a number of ways to produce rayon—for example, acetate rayon.

Man did not break completely with nature in producing fibers until about 10 years ago when some of the newer fibers began to emerge from the laboratory. Some of them, such as nylon, vinyl resin fiber, and vinylidene chloride fiber, are true synthetic fibers. Nylon and Vinyon came out about 1938 and Saran about 1940.

Casein fiber represents another important class of fibers introduced during the past 10 years—the new protein fibers. Casein is milk protein. Other proteins used for making fibers are those derived from soybeans, peanuts and corn.

Of the three great classes of man-made fibers—the cellulosic, the protein and the synthetic—the first was the only one that had been well established before the war. The synthetic and the protein fibers were just getting a foothold.

Let us introduce briefly some of these new fibers which are discussed more fully in other parts of the book.

One of them, nylon, has had more rapid commercial acceptance than perhaps any other fiber in a similar period. It has a number of outstanding properties which have been responsible for its rapid growth. They include high wet and dry strengths, toughness, excellent elasticity, and good resistance to chemicals, microorganisms and the like. Nylon was reserved for military uses during the war and production capacity was expanded to around 24 million lbs. annually, most of which was subsequently earmarked for the hosiery trades.

Another of the new fibers, one made from vinyl resin, is exceptionally resistant to corrosive action by chemicals. It is not attacked by concentrated acids or alkalis. Unlike most other synthetic fibers, it has as high tensile strength when wet as when dry. Thus far, vinyl resin fiber has been predominantly an industrial fiber.

An entirely different type of fiber, one made from glass, played an important role in the war effort. The industrial uses of glass fibers are too numerous to mention, but some idea of the growth of this material can be gained from the fact that value of output increased from 3 million dollars in 1939 to 55 million dollars

in 1944. Glass fiber is completely fireproof. If it had been used for draperies, it could have averted the disastrous night club fires in recent years. Glass fiber has unusually high strength and chemical inertness. If certain of its limitations can be overcome, it could go far in the textile field.

During the war, vinylidene chloride fiber was used for insect screens and other military purposes. It is one of the toughest and most chemically resistant of all fibers. In monofilaments, it can be made into colorful and durable upholstery that can be cleaned easily with soap and water. The recent development of vinylidene chloride multifilaments should extend greatly the field of applications.

A new fiber made of polystyrene was used during the war in radar and other military applications. Polystyrene fiber forms the basis of a new plastics structural material unusually light in weight and has possibilities for future use as a textile fiber.

Polyethylene fiber is the lightest of all fibers. It also has excellent resistance to mildews, so that it can be used to make marine ropes that will float in water.

Polyvinyl alcohol fiber will not float in water, but some forms dissolve in water. It has been used to make parachutes for mines laid at sea. The parachutes dissolve, leaving no trace of the mine. Polyvinyl alcohol can be made water-insoluble and used to make surgical sutures, which have excellent strength and durability.

A new form of rayon, a saponified cellulose acetate, is said to have greater tensile strength than any other textile fiber and to be stronger than an equivalent weight of steel wire. It was used during the war in applications where extreme strength, lightness and dimensional stability were required.

The basic significance of the new synthetic fibers lies in the fact that several of them are far superior to the natural fibers in important properties. During the war, the emphasis was placed on strength and other mechanical characteristics in which the synthetic fibers have a big advantage. Their dyeing properties were relatively unimportant. Cost was also unimportant, since

there was no limit to the price that would be paid for materials having the required qualifications.

In normal usage, emphasis is placed not so much on extreme strength, and the like, as on dyeing properties and other characteristics that are important to the consumer. This does not mean that a certain degree of strength is not needed, but rather that if a number of fibers are strong enough to meet ordinary requirements, other factors will be decisive.

In their present stage of development, nearly all the new fibers must be regarded as special-purpose, rather than general-purpose fibers. Even nylon, which has attained the largest volume of output of all the true synthetic fibers, is used principally for hosiery. The degree of specialization is also quite marked for the other synthetic fibers.

In general, the dyeing problems of the new fibers have not yet been fully solved. Nylon is not being featured in applications where color range is important. Vinylidene chloride and glass fibers do not dye very well, but are colored by incorporation of the pigment in the material itself, although in the case of glass fiber a method of surface dyeing has been worked out for certain colors. The vinyl resin fibers have also been handicapped by dyeing limitations.

This does not mean necessarily that the new fibers will remain special-purpose fibers. They are all undergoing intensive research and development, sponsored by financially powerful corporations. Gradually, they are being improved in properties and their costs of production are being reduced, relative to the natural fibers.

There is every reason to believe that the gradual improvement in quality and reduction in price of rayon, which has been achieved over a period of years, will be paralleled in the cases of the other man-made fibers. Rayon is next to cotton in price and this partly accounts for the fact that it is second only to cotton in volume of consumption. The fact that rayon is cheaper than both wool and silk has played no small part in helping it to surpass those two fibers in volume of production.

Some of the new fibers have already demonstrated their ability to compete with the established fibers on a price basis. Thus, nylon can compete with silk, and casein with wool. But all of the new fibers are still far above cotton and rayon in price.

All of them are still in an early stage of commercial development. Even those fibers which were introduced prior to the war had barely secured a commercial foothold before their production was diverted to military uses, or otherwise affected by factors having their origin in the war. The normal pattern of growth has not yet been established.

In attempting to outline the probable pattern of future trends in textile fibers, it is important to keep in mind their present proportionate distribution. In very approximate terms, the natural fibers account for around 90% of the total consumption of fibers; rayon for about 10% and the new synthetic fibers for less than 1%. Therefore, it is reasonable to expect that the synthetic fibers will show rapid growth from their present level at least for many years. Doubtless, rayon will continue its expansion but at a slower rate than in the past and also at a slower rate than the new fibers. Of course, on a poundage basis, the gains for rayon may be far greater than for the newer fibers.

The new synthetic fibers could have a many-fold increase from their present level of well under 1% of total volume of consumption, without making any serious inroads into the established fibers.

A factor that undoubtedly will have a decisive bearing on future trends is research. Growth trends are largely a reflection of relative research activities. The extent to which the established fibers will be able to hold their present markets will depend in large degree on the amount and effectiveness of their research efforts relative to their new competitors.

A recent development having great promise is the chemical treatment of fibers and textiles to improve their properties. By the application of suitable resins and other chemicals, cotton can be made stronger and tougher; wool can be made resistant to shrinkage. Many other special properties, such as resistance to

fire, water repellency and the like, can be imparted to textiles by chemical treatments.

Yarns can be coated with plastics to give them entirely new properties. Plastic-coated yarns have found many uses in recent years both in consumer wearing apparel where appearance is a decisive factor and in industrial applications where such yarns have been made to order to meet specific requirements.

Another revolutionary development, as yet quite limited in its scope of applications, is that of unwoven fabrics. Costly spinning and weaving operations have been eliminated in making certain types of fabrics which are coming into greater use for special types of applications.

In short, research is conducted in many different directions to create new fibers and fabrics. Not only are new fibers being created from a host of materials never before utilized for such purposes, but natural fibers are improved and new fabrics manufactured in entirely new ways.

While it is too early as yet to appraise the full significance of these new developments, there can be no question that their ultimate possibilities are tremendous. Man is beginning to break away from his long dependence on unimproved natural fibers. He can now make his fibers and fabrics to order. The time may come when all the fibers he uses will be either man-made or man-improved; that is, *new fibers*.

THE RELATIONSHIP BETWEEN PLASTICS AND FIBERS

There is a very close relationship between plastics and the new fibers. It is an axiom in the plastics industry that any material that can be made into a film can also be made into a fiber. In a sense, a manufactured fiber or filament is merely one form of an extruded plastic or resin. In this sense, the new fibers are but a branch of the rapidly growing tree of plastics. When a new plastic has been developed, it is only natural to inquire whether a fiber can be made of it.

The parallelism between plastics and fibers is very broad. Just as plastics are divided into three principal groups: the cellulosic

plastics, the protein plastics, and the synthetic resins, the new fibers follow the same general classification. The cellulosic plastics correspond roughly to the cellulosic fibers, or rayons. The first plastic, like the first manufactured fiber, was made of cellulose nitrate. This material is no longer used as a fiber, but is still used as a plastic. Cellulose acetate may be either a plastic or a fiber, as may ethyl cellulose, cellulose acetate butyrate, etc.

In the same way, the various protein plastics—casein, soybean, peanut, corn, and other products—may be made into fibers. In both fields, casein has been used longer than the others which are just emerging from the development stage.

When we come to synthetic resins and plastics, there is a host of materials from which to choose. Fibers can be made from a number of vinyl resins, vinylidene chloride, polystyrene, polyethylene, polyamides, and many others which are still in an experimental stage, such as the silicones. All the materials mentioned are thermoplastic, or heat-softening. The thermosetting resins, which are heat-hardened, are not very well suited for making fibers.

In general, a material will have much the same properties as a fiber and as a plastic, but this does not mean that it will have an equal chance of commercial success in both fields. Some of the properties required in a material for use as a plastic are quite different from those needed in a material for making fibers. Thus, a plastic material must have high resistance to moisture absorption, whereas a certain amount of moisture absorption is highly desirable in a fiber. Again, it may be advantageous in a plastic to have a lower heat-softening point than in a fiber. The plastic can be readily softened and molded, whereas the fiber must be able to resist temperatures used in ironing.

Most of the new fibers started their careers as plastics. This is true of cellulose nitrate which was first used as a plastic in 1875, but was not used for making rayon until 1884. Casein first appeared as a plastic in 1904, but did not come into use as a fiber until 1936. Cellulose acetate was introduced as a plastic in 1911 and as acetate rayon in 1919. The vinyl materials, vinylidene

chloride, polystyrene, and polyethylene all came into use as plastics years before they were first used as fibers.

One exception is nylon, which was developed specifically to meet the demand for a new fiber to replace silk. Its use as a plastic took place later and is still relatively small. While nylon as a fiber has sold at a competitive price with silk, its price as a plastic is very high compared with other plastics materials. This is an illustration of the fact that a material, which can be used either as a plastic or as a fiber, may be much more successful in one field than in the other. Incidentally, the first strictly plastics application of nylon was in bearings for rayon plants.

Still another type of relationship between plastics and fibers is the use of resins for coating fibers and textiles. Resins furnish a highly promising means for improving the properties of cotton, wool, rayon, and other textile materials. Cellulose derivatives have long been used for finishing textiles. More recently, vinyl resins have been employed to take the place of natural rubber in water-proofing. Very recently, melamine resins have been used to make woolen goods shrink resistant. The silicone resins are undergoing considerable experimentation for making fabrics water repellent. A list of the resins used in one form or another to improve the qualities of textiles would include the phenolic, urea, melamine, casein, vinyl chloride, polyvinyl alcohol, alkyd, silicone, and many others, as well as the cellulose derivatives.

In summary, the relationship between plastics and fibers is a twofold one. Plastics are furnishing an ever-increasing assortment of materials from which to make new fibers; at the same time, they are making possible improvements in the older fibers and helping them to maintain their competitive position.

CLASSIFICATION OF FIBERS

In a broad sense, all fibers may be considered as belonging to two general classes, (1) natural fibers and (2) manufactured fibers or filaments. The natural fibers include cotton, wool, silk, ramie, and many others of vegetable, animal, or mineral origin.

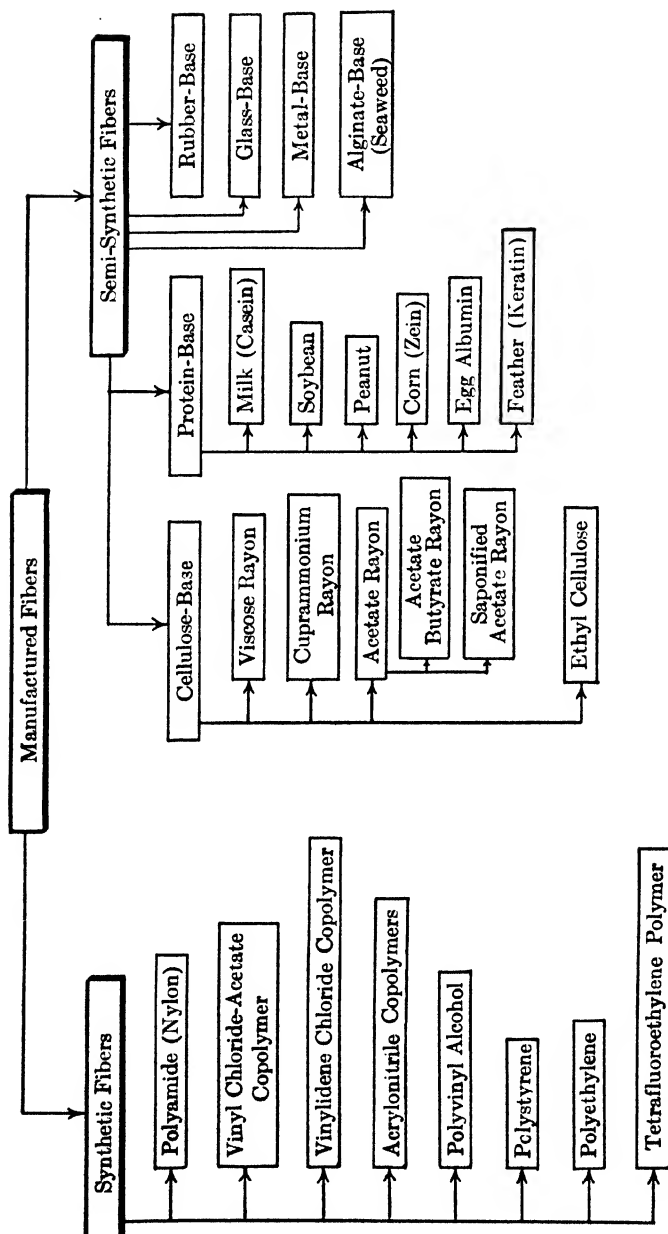


FIG. 3. Classification of Manufactured Fibers.

The manufactured fibers, as the term is used in this book, includes all the man-made fibers and filaments and covers not only the truly synthetic fibers and filaments, but also the semi-synthetics such as rayon, and protein fibers.

The term synthetic fiber has often been used loosely to include all of the man-made fibers, but, in our opinion, such usage is rather confusing. The term synthetic applies only to those fibers made from materials which are entirely built up or synthesized from their basic chemical elements. On the other hand, the semi-synthetics, such as rayon and the protein base fibers, are built up only partially from their constituent elements. For example, when rayon is made from cotton linters or wood pulp, the cellulosic component is not broken down and rebuilt, but its chemical identity is preserved while going through the various manufacturing processes. This is true when the cellulose radical is combined with the acetate radical to form acetate rayon. In a similar manner, the protein of milk or soybeans is not broken down into its chemical components when used to make protein base fibers. However, the protein is reacted with formaldehyde so that some chemical change does occur. For these reasons, the various types of rayon and protein fibers are included in this book under the term manufactured fibers, to distinguish them from the natural fibers, but they are not included under the term synthetic.

A well-known example of a synthetic fiber is nylon. The carbon is obtained from coal, the oxygen and nitrogen from the air, and hydrogen from water. These elements are synthesized to make adipic acid and hexamethylene diamine, which are combined under suitable conditions to form a polyamide, or nylon. In this case, there is a true synthesis or building up of a chemical compound from its basic elements.

Other examples of true synthetic fibers are vinyl resin (Vinylon), vinylidene chloride (Saran, Velon, etc.), polyethylene, polystyrene fiber (Polyfibre), polyvinyl alcohol fiber, and many others which are not so well known.

TABLE 1.1.—PROGRESS IN FIBERS

<i>Date</i>	<i>Fiber</i>
1884	Production of rayon begun in France.
1898	Cuprammonium process originated in Germany.
1911	Production of rayon started in United States.
1919	Production of acetate rayon started in United States.
1936	Lanital (casein fiber) introduced in Italy.
1938	Production of Vinyon (vinyl chloride—vinyl acetate copolymer) started by American Viscose Corp.
1938	Production of Fiberglas started by Owens-Corning Fiberglass Corp.
1938	Nylon introduced by E. I. du Pont de Nemours & Co., Inc.
1939	First large-scale commercial production of Aralac (casein fiber) by National Dairy Products Corp.
1940	Saran (vinylidene chloride) introduced commercially by The Dow Chemical Co.
1940	New fiber developed from seaweed in England.
1941	Fortisan production started in United States by Celanese Corp. of America.
1942	Typha (cattail fiber) introduced by Burgess-Manning Co.
1943	Elastic type Vinyon announced by American Viscose Corp.
1943	Soybean protein fiber announced by The Drackett Co.
1943	Aluminum yarn announced by The Reynolds Metals Co.
1944	Polyfibre (polystyrene fiber) announced by The Dow Chemical Co.
1944	Polyethylene announced by Carbide & Carbon Chemicals Corp.
1944	Ardil (peanut protein fiber) announced by Imperial Chemical Industries, Ltd., England.
1945	Stainless steel filament announced.

TABLE 1.2.—RELATIVE VOLUME OF ANNUAL FIBER CONSUMPTION IN THE UNITED STATES (1944)

	<i>Millions of Pounds</i>
Cotton	4,790
Rayon	705
Wool	622
Nylon	24
Casein	8
Vinylidene chloride	1
Vinyl resin	1—

CHAPTER II

Comparison of Fibers

SUMMARY

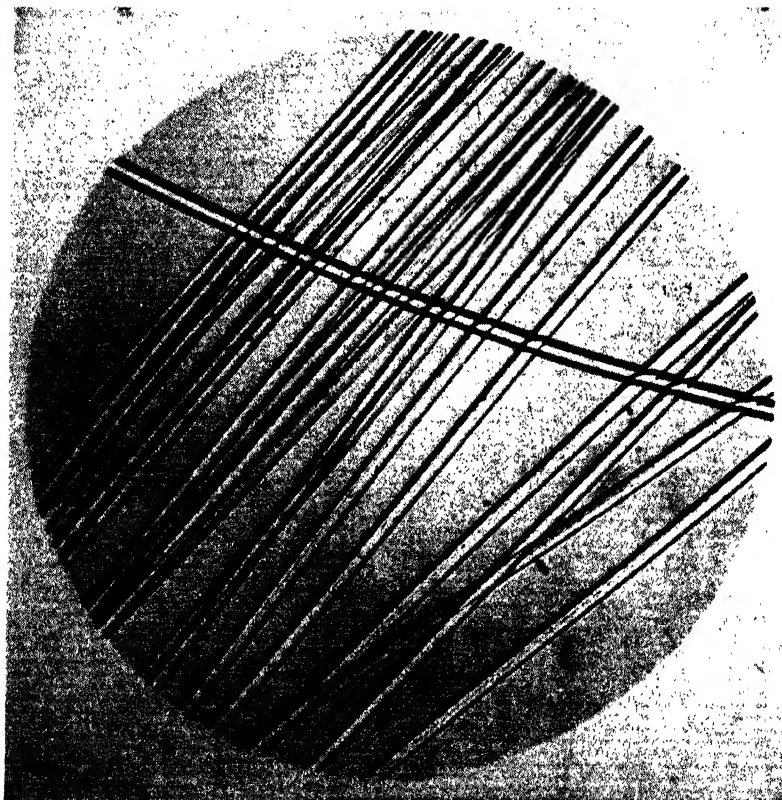
New synthetic fibers are at the top of the lists for strength, toughness, lightness, and resistance to chemicals, water, fire, insects and microorganisms. In each of these respects, one or more of the synthetics are superior to all the established textile fibers.

Perhaps the biggest advantage of the synthetics is that they can be produced in an endless variety of chemical types and physical forms making possible their adaptation to specific applications.

This does not mean that the new fibers are generally superior to the older fibers. In most applications, fibers are required that have a combination of useful properties. The widespread use of cotton and wool is based on their possession in satisfactory measure of a number of desirable characteristics.

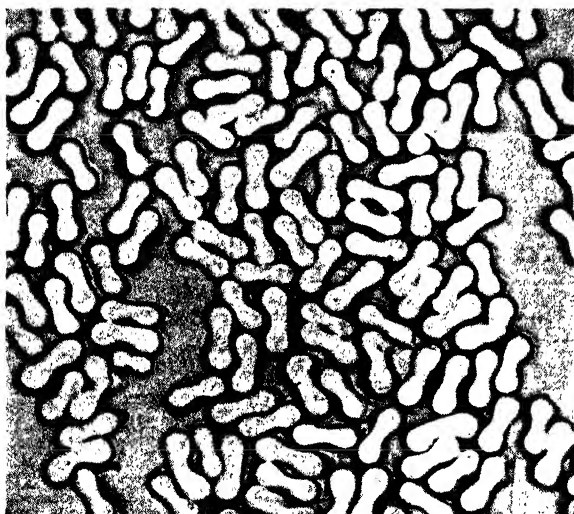
Thus far, no ideal general-purpose textile fiber has been developed and such may even be impossible of practical attainment. In fact, a fiber property which may be highly advantageous for certain purposes may be of serious disadvantage for other purposes. For example, a high degree of resistance to the effects of water and chemicals is an important asset of a number of the new synthetic fibers. But this very property makes them difficult to dye by the conventional methods. Again, a high degree of tensile strength is often associated with low elasticity and poor flexibility.

The most important single factor in determining the scope of application of any fiber is price. Most of the new fibers will have to be reduced sharply in price if they are to come into wide general use.



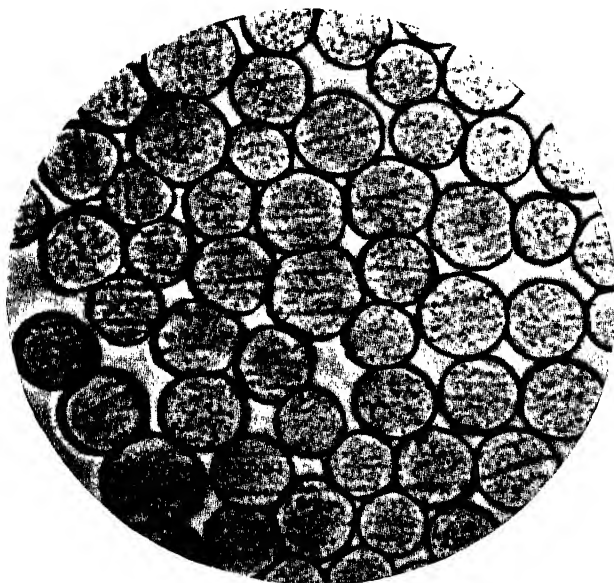
Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 4. A group of nylon filaments magnified.



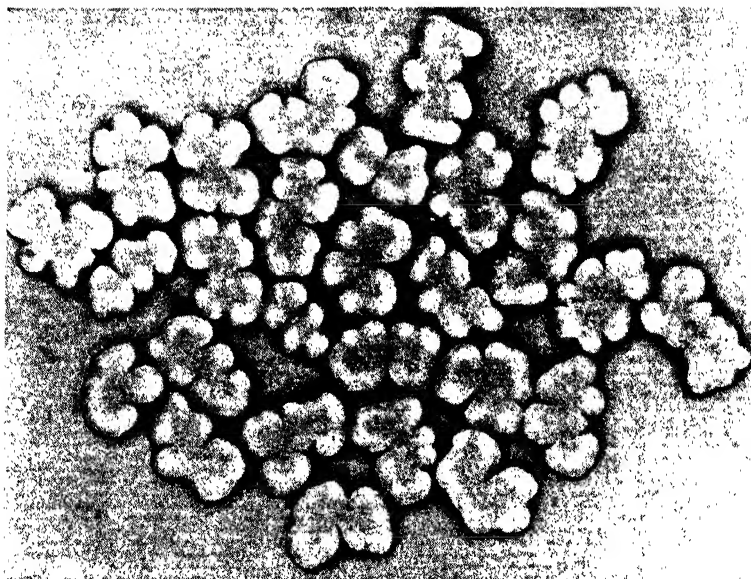
Courtesy American Viscose Corporation

FIG. 5. Cross-sectional view of Vinyon yarn (250 denier/216 filaments).

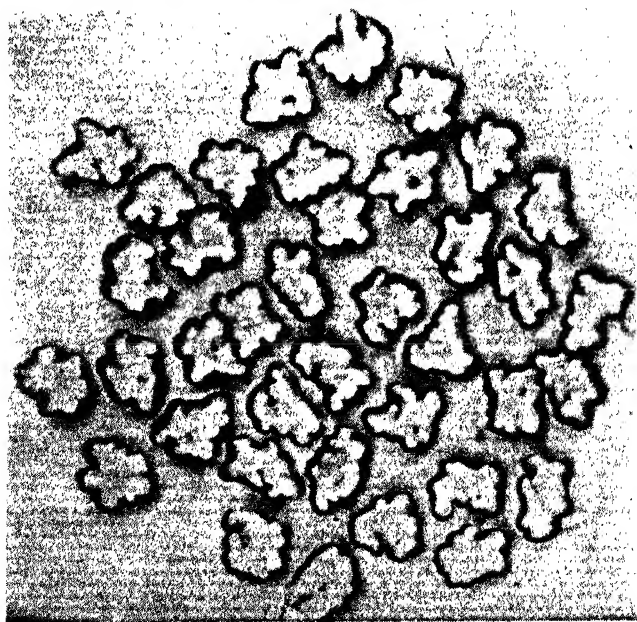


Courtesy W. M. Grosvenor Laboratories, Inc.

FIG. 6. Cross-sectional view of casein fibers (Aralac).



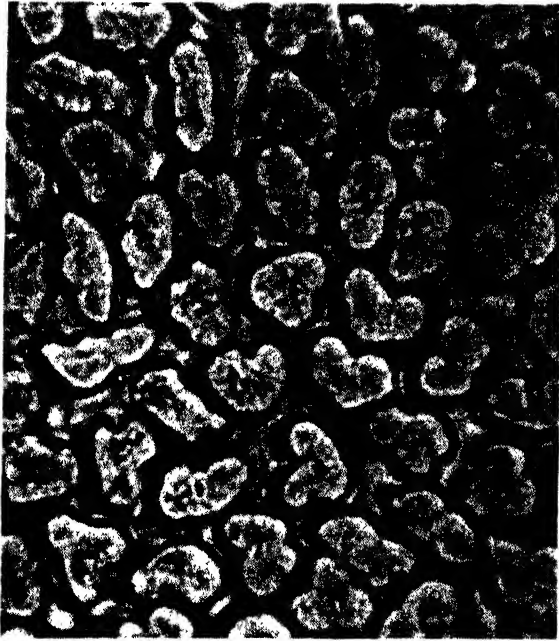
Courtesy American Viscose Corporation
FIG. 8. Cross-sectional view of acetate rayon yarn (100 denier/28 filaments).



Courtesy American Viscose Corporation
FIG. 7. Cross-sectional view of viscose rayon yarn (100 denier/40 filaments).

FACTORS IN COMPARISON

The introduction of many new types of fibers during the past ten years has extended greatly the range of fiber properties. In one property after another, a synthetic has shattered the record previously held by a natural fiber. Some fibers at the top of the



Courtesy Celanese Corporation of America

FIG. 9. Cross-sectional view of Fortisan yarn.

list only a decade ago have since fallen into a secondary or intermediate position.

All of this serves to emphasize that any comparison of fibers is subject to change. We are living in a dynamic world, not a static one, and research is continuously developing new fibers, as well as trying to improve those which are already in use. Therefore, a comparison which is valid today may not be valid tomorrow.

Nevertheless, a broad comparison of the various fibers on the basis of specific properties should prove very useful to those who want to know how to utilize them most effectively.

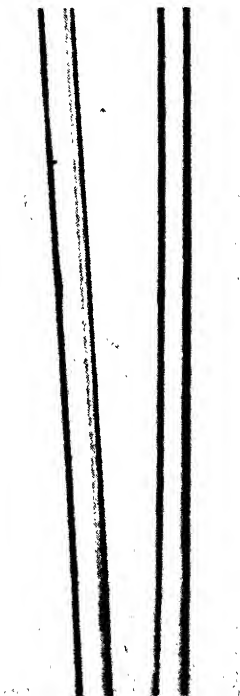
The basic properties of fibers, both physical and chemical, depend upon their chemical composition and fiber structure. However, the length of the fibers as well as the width and shape of their cross sections determine some of their physical characteristics.

The basic chemical structural units from which fibers are built are linked end to end in the fiber, forming molecules several hundred to many thousand units long. The orientation of these linear polymeric molecules lengthwise in the fiber leads to increased crystallinity of structure and higher strength. This orientation is natural for fibers such as cotton, but it is accomplished by stretching, drawing, or other special handling in the cases of the manufactured fibers.

The physical properties depend on the length of the molecules which go to make up the fiber, the manner in which these molecules are put together, and finally, their specific chemical structure. In a sense, the fiber bears the same relationship to its constituent molecules as a yarn bears to its constituent fibers. The prop-

erties of a yarn depend on the length of its fibers and on the manner in which they are put together, as well as on the basic properties of the fibers themselves.

Textiles made of continuous filaments are quite different in appearance and feel from those made of staple fibers. The width of a fiber affects the stiffness of fabrics made from it, as well as their draping qualities.



Courtesy of Celanese Corporation of America

FIG. 10. Longitudinal view of Fortisan filaments.

The shape of the cross section of a fiber also has an important effect upon the appearance and feel of the fabric. In some cases, it is round and smooth as in glass, nylon and vinylidene chloride fibers; in other cases, it is dumbbell shaped as in vinyl chloride—acetate resin fibers; and in others, it is dentated as in certain rayons. As contrasted with natural fibers, the variability of the manufactured fibers is almost unlimited. Moreover, very fine filaments, crimped filaments, hollow filaments, and rods and ribbons can be produced at will.

PROPERTIES

The manufactured fibers were in great demand during the war for various military purposes, where strength, flexibility and toughness were required. In these properties, the manufactured fibers far excelled the natural fibers. Comparison of the various fibers on the basis of important physical properties follows.

Specific Gravity. The range of specific gravities for fibers has been greatly extended in recent years by the introduction of new types. In fact, the heaviest of all fibers, stainless steel with a specific gravity of 7.8, and polyethylene, the lightest of all fibers, with a specific gravity of 0.92, have only recently been developed. Previously, the range of fiber specific gravities extended from 2.54 for glass to 1.14 for nylon. Both the heaviest and the lightest fibers are of manufactured origin and the natural fibers occupy an intermediate position.

The development of polyethylene fiber is of particular interest, since it is the only fiber that has a specific gravity of less than 1 and therefore floats in water.

Tenacity. Tenacity was a very important property in many fiber applications during the war, such as in nylon and saponified cellulose acetate parachutes, tow ropes, and the like. High-tenacity rayons were developed for use in tire cords. These high-strength fibers are finding many new peacetime applications.

Specific Gravity

Polyethylene	0.92
Nylon	1.14
Vinyl resin (Vinyon N)	1.2
Silk, degummed	1.25
Casein	1.29
Soybean protein	1.31
Wool	1.32
Acetate rayon	1.32
Vinyl resin (Vinyon)	1.35
Saponified acetate (Fortisan)	1.50
Flax	1.50
Viscose rayon	1.52
Cuprammonium rayon	1.52
Ramie	1.52
Cotton	1.54
Vinylidene chloride	1.72
Glass	2.54
Steel	7.8

The strength of the various fibers may be compared on two different bases—tenacity and tensile strength. The tenacity is generally expressed in terms of grams per denier (denier is equal to the weight in grams of 9000 meters of the fiber). It involves a measurement of strength in terms of denier, which is a unit of weight. On the other hand, the tensile strength is measured in terms of strength per unit of cross-sectional area.

An example will help to make this distinction clear. Tenacity in grams per denier ranges up to 8 for strong nylon and up to 7 for saponified cellulose acetate. This means that on the basis of equal weight, nylon is stronger than the saponified acetate. But the specific gravity of the former is only 1.14 compared with 1.50 for the latter, so that it takes a greater volume (or area of cross section) of the nylon than of the saponified acetate to obtain the same strength. If a comparison is made on the basis of tensile strength in pounds per square inch, that of saponified acetate (135,000 lbs. per sq. in.) is considerably higher than that of nylon (117,000 lbs. per sq. in.).

A useful general formula which expresses the relationship between tensile strength and tenacity is the following:

$$\text{Tensile strength (lbs. per sq. in.)} = \text{Tenacity (gms. per denier)} \times \frac{1}{12,800 \times \text{specific gravity.}}$$

Tenacity

	Dry (gms./den.)	Wet (% of dry)
Nylon (high tenacity)	6.0-8.0	84-90
Saponified acetate (Fortisan)	5.0-7.0	86
Ramie	6.7	130-160
Glass	6.5	92
Cotton, Sea Island	4.4-6.3	110-130
Nylon (reg.)	4.5-5.7	84-90
Cotton, American Egyptian	4.2-5.5	110-130
Silk, degummed	2.8-5.0	75-90
Cotton, American Upland	3.0-4.9	110-130
Viscose rayon (high ten.)	3.4-4.6	61-65
Vinyl resin, Vinyon (high ten.)	3.5-4.0	100
Viscose rayon (med. ten.)	2.5-2.9	62
Vinyl resin, Vinyon (reg.)	2.0-2.8	100
Vinylidene chloride	1.8-2.5	100
Viscose rayon (reg.)	1.8-2.4	45-55
Cuprammonium rayon	1.7-2.3	55
Acetate rayon (reg.)	1.3-1.7	60-70
Wool	1.2-1.7	80-90
Casein	0.6-0.8	40-50
Soybean protein	0.6-0.7	35-50

On the basis of tenacity (grams per denier), the strongest fibers are nylon, saponified acetate rayon, ramie, and glass fiber. It is noteworthy that the two fibers at the top of the list in tenacity are manufactured rather than natural.

The natural fibers generally occupy an intermediate position with respect to tenacity, although certain grades of cotton rank quite high. Wool is far down on the list for tenacity but has many other desirable properties, which account for its widespread use. Casein and soybean protein fibers have a lower tenacity than wool.

On the basis of tensile strength (pounds per square inch), glass fiber ranks first. Saponified acetate rayon also has very high

tensile strength, as already mentioned. Here, again, the natural fibers generally occupy an intermediate position.

An important consideration is the degree of strength a fiber retains when wet, compared with its dry strength. It is interesting that cotton and ramie are even stronger when wet than when dry, but most other fibers have a lower wet than dry strength. Important exceptions are vinyl chloride—acetate resin and vinylidene chloride fibers which have the same strength both dry and wet.

Tensile Strength

	<i>Thousands of lbs./sq. in.</i>
Glass	213
Saponified acetate (Fortisan)	96-135
Ramie	130
Cotton	59-124
Nylon	65-117
Viscose rayon	35-90
Silk, degummed	45-80
Vinyl resin (Vinyon)	35-69
Vinylidene chloride	40-55
Cuprammonium rayon	33-45
Acetate rayon	22-29
Wool	20-29
Peanut protein (Ardil)	14
Casein	10-13
Soybean protein	10-12

Certain fibers lose most of their strength when wet. This is particularly true of casein fiber which has a wet strength of from 40 to 50% of its dry strength, and soybean protein fiber with a wet strength of from 35 to 50% of its dry strength. In this respect, these manufactured protein fibers are distinctly inferior to wool, which retains around 85% of its dry strength when wet.

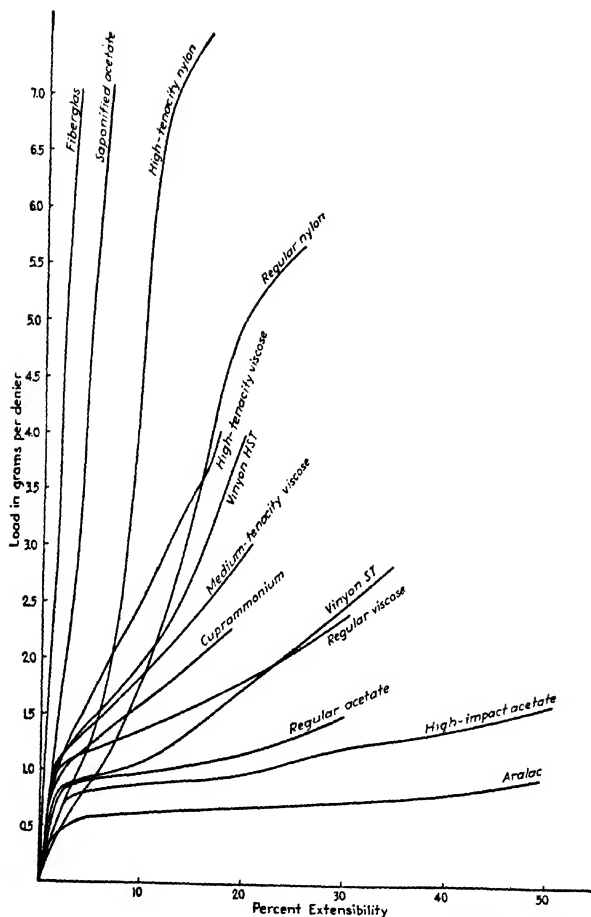
Extensibility. In general, the stronger a fiber is, the less extensible it will be. This can be seen by comparing the tables of tenacity and extensibility. Wool, casein, and soybean protein fibers are near the top of the list for extensibility. On the other hand, glass fiber, saponified acetate rayon, and certain other very strong fibers are among the least extensible.

Comparison of Fibers on Basis of Tenacity and Tensile Strength

<i>Fiber</i>	<i>Specific Gravity</i>	<i>Tenacity (gms./den.)</i>	<i>Tensile Strength (thousands of lbs./sq. in.)</i>
Nylon	1.14	4.5-8.0	65-117
Silk, degummed	1.25	2.8-5.0	45-80
Casein	1.29	0.6-0.8	10-13
Soybean protein	1.31	0.6-0.7	10-12
Wool	1.32	1.2-1.7	20-29
Acetate rayon	1.32	1.3-1.7	22-29
Vinyl resin (Vinyon)	1.35	2.0-4.0	35-69
Hemp	1.49	5.9-6.9	112-132
Jute	1.49	3.0-5.9	57-112
Flax	1.50	2.7-7.8	52-150
Saponified acetate (Fortisan)	1.50	5.0-7.0	96-135
Viscose rayon	1.52	1.8-4.6	35-90
Cuprammonium rayon	1.52	1.7-2.3	33-45
Ramie	1.52	6.7	130
Cotton	1.51	3.0-6.3	59-124
Vinylidene chloride	1.72	1.8-2.5	40-55
Glass	2.54	6.5	213

Extensibility

	<i>Elongation at Break (%)</i>	
	<i>Dry</i>	<i>Wet</i>
Wool	30-50	30-60
Casein	30-50	85-120
Soybean	30-40	60-70
Vinyl resin (Vinyon)	18-35	18-35
Vinyl resin (Vinyon N)	30	30
Acetate rayon	23-30	30-38
Vinylidene chloride	20-30	20-30
Silk	13-20	...
Nylon	12-20	13-26
Viscose rayon	9-20	14-35
Cotton	3-7	...
Saponified acetate (Fortisan)	6-6.5	6-6.5
Ramie	3-7	...
Glass	2-3	1-2



Courtesy Textile World

FIG. 11. Typical stress-strain curves of manufactured fibers.

Recovery on Unloading. This refers to the recovery of fibers when subjected to a tensile load and then unloaded. The extent of recovery depends upon the elongation, the time the load was on, and the time it was off.

Glass, nylon, vinyl chloride-acetate resin, vinylidene chloride and silk fibers rank high in recovery. The recovery of casein fiber is less than that of wool.

*Recovery on Unloading**

	When Elongated (%)	Recovery	
		(%)	(seconds)
Glass .....	..	100	...
Nylon	1	82†	60
	2	63†	60
	4	73	60
	8	100	60
	16	91	60
Vinyl resin (Vinyon) .....	...	96	After a time
	Up to 80	90	Immediately
Vinylidene chloride .....	...	95	...
Silk	1	82†	60
	2	74†	60
	4	76	60
	4	59†	60
	8	56	60
	16	47	60
Casein (Aralac) .....	...	Less than wool	...
Viscose rayon (reg.)	4	74-80	...
	14	58	...
Acetate rayon	4	65-50	...
	14	29	...

* Source: "A Survey of the Synthetic Fibers," Wm. D. Appel, *Am. Dyestuff Reporter* 34, 21 (January 15), 1945.

† Against a load of 0.25 gms./denier.

Stiffness. Stiffness is the resistance to deformation. Glass fiber stands at the top of the list of relative average fiber stiffness. Six natural fibers rank next: flax, hemp, jute, abaca, ramie and sisal. Then come some of the high-strength rayons. Cotton is about intermediate in position while wool is low.

*Relative Stiffness of Fibers**

<i>Fiber Material</i>	<i>Average Stiffness</i>
Glass	290
Flax	270
Hemp	200
Jute	185
Abaca (Manila "Hemp")	175
Ramie	167
Sisal	127
Saponified acetate (Fortisan)	105
Viscose rayon (Fiber G)	75
Cotton	57
Nylon (high ten.)	41
Silk (Tussah)	24
Viscose rayon (high ten.)	23
Nylon (reg.)	22
Vinyl resin (Vinyon) (high ten.)	22
Vinylidene chloride	18
Silk, degummed	15
Viscose rayon (med. ten.)	15
Cuprammonium rayon (reg. ten.)	14
Viscose rayon (reg. ten.)	10
Vinyl resin (Vinyon) (reg. ten.)	7
Acetate rayon (reg. ten.)	5
Wool	4
Acetate, high-impact	3
Cascia	2

* Source: "Textile Fibers—An Engineering Approach to Their Properties and Utilization," Harold DeWitt Smith, Edgar Marburg Lecture, 1944.

Toughness. Toughness is the amount of work required to rupture the fiber material. Some of the manufactured fibers are at the top of the list of relative toughness index. Vinylidene chloride fiber ranks first, followed by nylon. Silk stands quite high in toughness and far above the other natural fibers. Glass fiber, despite its great strength, is not very tough, as the fibers when rubbed together are easily broken.

*Relative Toughness of Fibers**

<i>Fiber Material</i>	<i>Toughness Index</i>
Vinylidene chloride	56
Nylon (reg.)	45
Nylon (high ten.)	41
Silk, degummed	40
Acetate, high-impact	32
Silk (Tussah)	30
Vinyl resin (Vinyon) (reg. ten.)	30
Vinyl resin (Vinyon) (high ten.)	25
Viscose rayon (high ten.)	20
Wool	20
Viscose rayon (medium ten.)	19
Saponified acetate (Fortisan)	19
Viscose rayon (reg. ten.)	17
Acetate rayon (reg. ten.)	16
Cotton	14
Casein	14
Viscose rayon (Fiber G)	14
Cuprammonium rayon (reg. ten.)	13
Ramie	8
Abaca (Manila "Hemp")	7
Glass	6
Flax	6
Sisal	5
Hemp	4
Jute	2

* Source: "Textile Fibers—An Engineering Approach to Their Properties and Utilization," Harold DeWitt Smith, Edgar Marburg Lecture, 1944.

Other Properties. The chemical properties of the various fibers are determined by their basic chemical composition. The various forms of rayon, having a cellulosic base like cotton, have chemical properties similar to cotton, although their physical properties are quite different. Casein, soybean protein, and peanut protein fibers being quite similar to wool in chemical composition, have many of the chemical properties of wool. Synthetic fibers can be made with an unlimited range of chemical properties.

Vinylidene chloride polymer and vinyl chloride-acetate resin fibers are in general not affected by acids or alkalis and are re-

sistant to many other chemicals. Nylon and glass fibers also have a high degree of chemical resistance. Glass fiber is unaffected by almost all chemicals except hydrofluoric acid.

The stability of the manufactured fibers to light varies from fair to good, depending upon chemical composition, just as in the cases of the natural fibers. With the exceptions of the regenerated cellulose and the protein base fibers, the manufactured fibers are highly resistant to attack by mildews and other microorganisms that damage the natural fibers.

The manufactured fibers show considerable variation in their reaction to heat. Glass fiber has a high softening point, considerable thermal stability and is incombustible. Nylon, cellulose acetate, vinylidene chloride polymer, vinyl chloride-acetate resin, and polyethylene fibers are thermoplastic—they soften when subjected to appropriate degrees of heat. However, they vary in their softening points, thermal stability, and combustibility. The thermoplasticity of these fibers is a disadvantage for certain uses, but has been utilized in the production of textiles which do not crease readily or which hold a crease or pleat even when laundered.

Softening Points of Thermoplastic Fibers

Degrees F.

Glass	1540 (approx.)
Nylon	450-480
Acetate rayon	400-445
Vinylidene chloride	240-280
Ethyl cellulose	210-265
Polyethylene	220-230
Polystyrene (Polyfibre)	190-230
Vinyl resin (Vinyon)	167-176

Regarding flammability, the following conclusions are based on recent tests made by the American Association of Textile Chemists and Colorists:

1. Wool, silk, nylon, vinyl resin, and vinylidene chloride polymer fabrics offer no flammability hazard.

2. Cotton is just as flammable as regenerated type rayon (viscose and cuprammonium rayons) under identical construction and testing conditions.

3. Since cotton has a normal moisture content of 6.5%, compared with 11% for regenerated type rayon, it is reasonable to conclude that cotton will come to the critical point much more rapidly than rayon.

4. Acetate rayon fabrics, both close knit or woven and pile fabrics, gave no flash or burning test. However, acetate rayon netting, even though the rate of burning was relatively slow and the volume of flame small, did burn, dropping a residue of still burning molten material through the grid. It has also been found that acetate rayon even though relatively nonflammable, when treated with some flame-retardant chemicals, becomes quite flammable.

5. Certain coated fabrics, although generally slow to ignite, burn with a violent flame which is difficult to extinguish and therefore offer a very definite hazard.

Some of the synthetic fibers show very low moisture absorption, because of the absence of OH groups in their structure. Vinyl chloride-acetate resin, vinylidene chloride polymer, and glass fibers hold 0.1% or less moisture when saturated. Nylon fiber holds about 6%. These fibers swell very little, if at all, in water, and they dry very rapidly.

Casein and soybean protein fibers are similar to wool in moisture absorption. The cellulosic fibers such as cotton, cuprammonium and viscose rayons, absorb moisture from the atmosphere, as a result of the OH groups in the composition of these fibers. Polyvinyl alcohol fiber, for the same reason, is soluble in water.

Certain synthetic fibers do not readily soil and are easily cleaned because of their chemical inertness and their smooth surface. Vinylidene chloride polymer and nylon are outstanding in these respects.

The dyeing properties of the various fibers are closely related to their chemical composition. The absence of OH, COOH, and NH groups in vinyl chloride-acetate resin, vinylidene chloride

polymer and glass fibers accounts for their lack of affinity for dyes. However, methods of coloring these fibers are being developed successfully. One method involves the addition of pigments before extrusion. Surface dyeing is also being applied.

The rayons, except the acetate, take the same dyes as cotton. Acetate rayon and nylon require special dyestuffs and processing. The manufactured protein fibers take the same dyes as wool.

*Modulus of Elasticity of Fibers**

	10 ¹⁰ Dynes per sq. cm.		
	Static Method	Dynamic Method	Velocity of Sound Method
Quartz .....	...	...	128.69
Silk, degummed	8.8-6.9	...	14.4
Silk, 47.5% relative humidity	9.8	...	...
80% relative humidity	-6.2	...	...
90% relative humidity	-5.0	...	...
Cotton, mercerized	7.85	...	...
Cotton, 65% relative humidity	-5.9	...	...
50% relative humidity	-5.2	...	...
Viscose rayon	8.3-5.9	11.5	14.7 ^a
...	7.3 ^b	...	11.5 ^a
...	...	...	1.3 ^d
Viscose, strong	10 ^b	33.3	44.5 ^a
...	...	...	33.8 ^c
...	...	...	8.8 ^d
Acetate rayon	4.9-3.15	...	6.1 ^c
...	...	...	1.7 ^d
...	8.3 ^b	...	...
Wool	3.9-2.5	...	5.1
Polyamide, 0% relative humidity	4.95-4.8	...	...
50% relative humidity	3.1	...	...
100% relative humidity	1.17	...	...

* Source: "A Survey of the Synthetic Fibers," Wm. D. Appel, *Am. Dyestuff Reporter* 34, 21 (January 15), 1945.

^a Dried. ^b Measured at very short times. ^c Air dried. ^d Wet.

Chemical Modification of Fibers. The chemical formulas indicate many ways in which both the natural and man-made fibers can be modified. For example, cotton (cellulose) can be modified through substitution of the acetate radical for hydrogen in

some of its OH groups. The resulting acetate rayon (cellulose diacetate) is only one of several derivatives of cellulose which have attained commercial importance. Other cellulose derivatives which have been made into fibers are ethyl cellulose and cellulose acetate butyrate. Saponification of acetate rayon under suitable conditions yields a regenerated cellulose type of rayon, such as Fortisan, which is one of the strongest of all fibers.

*Basic Properties of Textile Fibers**

Textile Fiber	Specific Gravity	Refractive Indices		Specific Index
		η_x^a	η_y^b	
Wool (dry at 25° C.)	1.304 ^c	1.556	1.547	+0.009 ^d +0.010 to +0.0120 ^e +0.017 ^f
Cotton (dry at 20° C.)	1.550 ^g	1.580	1.533	+0.053 ^d +0.0180 to +0.0569 ^e +0.005 ^d
Silk (degummed) (dry at 20° C.)	1.253 ^g	1.591	1.538	+0.026 ^d ...
Acetate (dry at 20° C.)	1.33 ^g	1.478	1.473	+0.060 ^d ...
Viscose (bright) (dry at 20° C.)	1.534 ^f	1.547	1.521	...
Vinyon	1.34 to 1.36 ^h	1.536	1.536 ^h	...
Nylon	1.14 ⁱ	1.580	1.520	+0.060 ^j ...
Glass (at 30° C.)	2.557 ^k	1.545	1.545 ^k	...

* Source: A.S.T.M. Standards on Textile Materials, October 1944.

^a Indices for light vibrating perpendicular to the long-fiber axis.

^b Indices for light vibrating parallel to the long-fiber axis.

^c A. T. King, "The Specific Gravity of Wool and Its Relation to Swelling and Sorption in Water and Other Liquids," *Journal, Textile Inst.*, Vol. 17, pp. T53-T67 (1926).

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^h Carbide and Carbon Chemicals Corp., unpublished data.

ⁱ E. Clayton, "Nylon," *American Dyestuff Reporter*, Vol. 28, pp. 196-198 (1939).

^j A. Frey-Wyssling, "Optics of the Artificial Fiber, Nylon," *Nature*, Vol. 145, p. 821 (1940).

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^l A. C. Goodings and L. H. Turi, "The Density and Swelling of Silk Filaments in Relation to Moisture Content," *Journal, Textile Inst.*, Vol. 31, pp. T69-T80 (1940).

Synthetic fibers can be modified to an even greater extent through appropriate changes in chemical formulation. By vary-

ing the proportions of vinyl chloride and vinyl acetate in vinyl resin fibers, the properties can be made to order to meet specific needs. This is also true for other copolymer fibers, such as vinylidene chloride—vinyl chloride. Many types of nylon fibers differing in their properties are possible through choice of raw materials used in their manufacture and the degrees of their polymerization.

PRICES

The most important single factor in comparing fibers is price. It is no exaggeration to say that price is equal in importance to all the properties of a fiber combined, since it is a measure of the value of all the properties. No matter how good the properties of a fiber may be, it must sell at a reasonable price if it is to have widespread acceptance.

The popularity of rayon is to a large extent due to its low price. One of the most significant developments of recent years has been the gradual narrowing in the price differential between viscose staple fiber and cotton until they are on a directly competitive price basis.

But prices of most of the other man-made fibers are still quite high. They must be reduced considerably if they are to gain widespread acceptance. Probably the fibers that will show the greatest growth in the future will be those which can be reduced the most in price.

Typical Prices of Various Fibers (Per Pound)

Cotton	\$0.25
Viscose rayon staple	0.25
Acetate rayon staple	0.38
Viscose rayon yarn	0.55
Acetate rayon yarn	0.56
Aralac (casein fiber)	0.64
Wool	1.18
Vinyon yarn (vinyl chloride-acetate)	1.35
Fiberglas yarn	1.50
Nylon hosiery yarn	2.75
Fortisan yarn (saponified cellulose acetate)	2.80

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Courtesy Pepperell Manufacturing Company

FIG. 12. High in a parachute loft at an Air Corps base nylon parachutes and shrouds are hung to be aired and dried.

CHAPTER III

Nylon

SUMMARY

Nylon was introduced in the fall of 1938. By 1945 it had attained an annual production rate of 24,000,000 lbs., second only to rayon among the manufactured fibers. But it took rayon, which had been introduced in 1911 until 1922 to reach 24,000,000 lbs. What rayon did in eleven years, nylon did in seven.

Nylon's rapid acceptance has rested upon its possession of certain desirable properties to a marked degree. Its tenacity, dry, ranges from 4.5 to 8.0 grams per denier, considerably higher than that of any natural fiber and higher even than that of the high-strength types of rayon used in tire cords. Unlike rayon, nylon loses little of its strength when wet, retaining 85% of its dry strength. In another important physical property, elasticity, it surpasses most of the natural fibers and rayon, a factor of major importance in connection with its use in hosiery. It also has high resistance to abrasion.

Another advantage of nylon is that it can be permanently set or shaped when heated with hot water or steam. However, its melting temperature (482° F.) is considerably above that of other heat-softening fibers.

Chemically, it is highly resistant to alkalies and is unaffected by ordinary dry-cleaning solvents. However, it is attacked by mineral acids. It is resistant to mildew and microorganisms, but is damaged by moths and ants.

Nylon has certain properties that give it an advantage in some uses, but place it at a disadvantage in others. It absorbs much

less moisture than other common fibers, a property which would be advantageous in raincoats but disadvantageous in towels. Thus, nylon stockings dry more quickly than silk and rayon stockings, but feel clammy when dry and slippery when wet.

Nylon's electrical qualities have led to its use in the forms of both yarns and coatings for insulating wires. But it has the disadvantage of easily becoming charged with static electricity, which sometimes causes trouble during processing.

Fabrics made of nylon deteriorate from exposure to sunlight at the same or a greater rate than cotton or rayon, but less rapidly than silk.

Finally, nylon is still quite expensive, although substantial price reductions have been made and undoubtedly will continue in the future. Its position might be summarized by saying that in many ways it is superior to most other fibers, but at a price.

Definition. On May 9, 1945, the Executive Committee of E. I. du Pont de Nemours & Company revised its former definition of nylon and adopted the following definition:

A generic term for any long-chain synthetic polymeric amide which has recurring amide groups as an integral part of the main polymer chain, and which is capable of being formed into a filament in which the structural elements are oriented in the direction of the axis.

The term "nylon" is not limited to the type used for making textile fibers. It is applied also to other types of nylon which can be made into sheets, bristles, molded plastics, coatings for fabrics and wires, and other products.

HISTORY AND DEVELOPMENT

The development of nylon by the Du Pont Company goes back to 1927, when Dr. C. M. A. Stine, who was then Chemical Director, foresaw the need of a broader program of research to provide new products which would insure the future growth of the company. The management thereupon decided to embark upon fundamental research as an essential activity.

As early as 1929, it was the goal of Du Pont research to create a distinctly new fiber. Attention was first directed to a study of cellulose derivatives, particularly the ethers and new types of esters. These materials, although capable of being spun into yarns, appeared to offer no significant advantages in properties or cost compared with the known types of rayon.

During the course of this investigation, certain nitrogen-containing derivatives of cellulose were prepared with the thought that amino or substituted amino groups would modify the properties of cellulose, particularly its dyeing characteristics and, in this respect, make it approach more closely to silk or wool. This investigation, however, was ultimately unsuccessful.

While this work was under way, another group of research chemists, under the direction of Wallace H. Carothers, were studying the subject of polymerization by condensation and the structure of high molecular weight compounds. This proved to be an unusually fertile field in which there had been little previous investigation. This study of polycondensation, whereby linear polymers are produced, led eventually to the invention of nylon.

The research activities preceding the manufacture of nylon yarn can be divided into three periods:

1. Fundamental research activities which provided the foundation for the development.
2. Concentration of attention on polyamides, which lead to the synthesis of a polymer having properties suitable for use as a new fiber.
3. The development of practical processes for the manufacture of intermediates and polymer, and for the spinning of fibers.

At first, the study was wholly fundamental in character—designed to throw further light on certain aspects of polymerization. But the rather striking properties of fibers obtained from superpolyesters aroused the hope that it might be possible to make a fiber of commercial utility from some type of synthetic linear superpolymer. Thereafter, research was directed to this practical end.

Polyamides were prepared from a variety of amino acids, and also from dibasic acids and diamines. The material obtained by the combination of adipic acid and hexamethylene diamine and by their controlled polymerization at high temperatures was termed polymer 66, because there are six carbon atoms each in the adipic acid and the diamine. Early in 1935, the very first nylon filaments were made by squirting the molten polymer through a hypodermic needle. The cooled filaments could be stretched several times their original length without breaking. The cold drawing, as this process is now termed, made the filaments more transparent, more lustrous, and much stronger.

Polymer 66 was selected for initial manufacture because it had the best balance of properties and manufacturing cost of the polyamides then known. Before this nylon yarn could be manufactured in commercial quantities, new machinery had to be designed and built. Radically new engineering developments were involved because of the peculiar circumstances under which the yarn had to be spun.

After many trial runs on a laboratory scale, nylon yarn was made for an experimental batch of stockings, in April 1937. In July 1938, a pilot plant began operation. Toothbrush bristles were placed on sale throughout the country in the fall of 1938, at which time the new synthetic was named *nylon* and its whole development announced to the public.

COMMERCIAL ACCEPTANCE

Nylon is unique among the synthetic fibers in having gained commercial acceptance before the war. In fact, there was a ready market in the hosiery field waiting for it when it was first introduced. The progress of nylon can be traced quite clearly from the annual reports to stockholders issued by the Du Pont Company.

The first unit of the nylon yarn plant at Seaford, Del., commenced operations December 15, 1939. This unit had a capacity to manufacture, annually, approximately 4 million lbs. of yarn.

Plans were prepared in 1939 for construction of a second unit of equal capacity.

Various manufacturers had already been supplied with yarn, made in the pilot plant at the Experimental Station at Wilmington, for experimental knitting, weaving, and dyeing. Hosiery manufacturers had already made thousands of pairs of nylon stockings and were satisfied as to their excellent wearing qualities. Nylon in the form of monofilament had met with success when made into bristles for use in tooth brushes, other toilet brushes, and in special types of industrial brushes. It was used also for fishing leaders and surgical sutures, as well as in the form of sewing thread and fishing lines.

In 1940, nylon yarn won wide public acceptance in its first full year on the market. It was used principally by hosiery manufacturers, who made about 35 million pairs of women's stockings, and by the end of the year stockings were being manufactured at the rate of 68 million pairs annually. The yarn was also used in the manufacture of men's socks. Additional applications mentioned in 1940 for the monofilament were racket strings and insulation in coverings for electrical wires.

Significantly, the first military applications were parachute safety belts, straps and cords for the aviation industry.

The second unit of the nylon yarn plant at Seaford, Del., began operations in November 1940, and construction of an additional plant at Martinsville, Va., was started in December. In November, the price of nylon was reduced about 4%.

Production in 1941 was approximately 170% greater than in 1940 and hosiery manufacturers used nylon yarn in more than 109 million pairs of women's stockings compared with 35 million pairs in the preceding year. The yarn was used also in the manufacture of many other kinds of wearing apparel, and the monofilament found increasing uses for racket strings, surgical sutures, and bristles for many kinds of brushes. There was a rapidly growing demand for nylon yarn for military applications previously dependent upon silk and linen.

When an embargo was placed on silk late in 1941, followed by war with Japan, facilities for the manufacture of nylon yarn were expanded rapidly. The entire output of the two yarn plants was reserved by the Government for military purposes, to the exclusion of its use for hosiery and other civilian goods.

Production was increased substantially in 1942 and 1943, with the entire output going into such military items as parachute fabrics, airplane tire cords, and glider tow ropes.

Nylon filaments helped to relieve the shortage of Asiatic pig bristles, once used extensively in all kinds of brushes. A new tapered nylon bristle was developed for paint brushes. The taper was achieved by pulling the filament from the spinneret at varying rates of speed. It is claimed that the bristles wear three times as long as natural bristles.

Production of the yarn and other nylon products showed a further substantial increase in 1944, all material remaining under allocation. During the year, military applications became more diversified. The use of nylon cord in aircraft tires assumed greater importance. Other military applications were based upon the fact that nylon withstands the effects of humid climate, such as mildew and mold. It was made into mosquito netting and screening, hammocks, clothing, and shoe laces for use in the South Pacific. Of more general use were plasma filters, tents, ponchos, pick-up and tow ropes, as well as special apparel for the fighting forces.

When the war ended in August 1945, and Government orders were cancelled, Du Pont quickly resumed the production of nylon for civilian purposes. Nylon yarn, the entire output of which had been used for military purposes since 1942, began to flow again to hosiery manufacturers and other branches of the textile industry.

During the war period, nylon productive capacity had been greatly expanded to an annual 24,000,000 lbs. Since then, about 23,000,000 lbs. have been earmarked for the hosiery trade. Further additions to capacity are under way.

MANUFACTURE

The production of nylon starts at an ammonia plant, where high-pressure synthesis converts certain gases and coal tar fractions into adipic acid and hexamethylene diamine. One of the intermediate chemicals used is ammonia, which is also made by high-pressure synthesis. The elements entering into these compounds are carbon (from coal), nitrogen and oxygen (from air), and hydrogen (from water). Hence, the popular characterization of nylon as a product of coal, air and water.

The adipic acid and diamine solutions are run together, in measured amount, into a stainless steel kettle. The chemicals combine to form nylon salt, hexamethylene-diammonium-adipate. The concentrated salt solution is charged into a cylindrical autoclave where polymerization is carried out. Stabilizers are added in order to control the molecular weight and viscosity. Long-chain linear polymers are formed having molecular weights ranging from 10,000 to 25,000.

After polymer formation, molten nylon is extruded as a ribbon on a chilled roll, and the ribbon is cut into small chips. This permits a convenient form for storage, handling, and blending of various batches to insure uniformity of the product.

The nylon chips are put into the hopper of the spinning unit and dropped on a heated grid (285° C.) where the polymer melts. In the molten condition, it is pumped and metered by specially designed pumps and finally filtered through special filter packs before passing through the spinneret to form filaments. All parts of the equipment must be maintained at a temperature above the melting point of the polymer. In the molten condition, nylon polymer is blanketed with an inert gas (purified nitrogen) to prevent any undesirable effects from oxygen at the elevated temperature.

By the pressure of the pumps, the molten nylon is extruded through the tiny holes of the spinneret. The filaments thus formed harden quickly on striking the air outside the spinneret

and are drawn off at the rate of about 3000 feet per minute. The filaments then converge and pass into a conditioner which moistens them sufficiently to make them stick together as a single thread.



Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 13. Molten nylon polymer, extruded on this huge casting wheel, is sprayed with water, which helps it to solidify into a strip resembling ivory. In later operations, it is chopped, melted and extruded again as filaments.

During the wind-up process, the yarn passes over a lubricating roll, which puts a finish on the surface. This also helps the filaments to stick together and prevents the accumulation of static electricity.

At this stage, the filaments are in an undrawn condition and do not exhibit the high tensile strength and elasticity inherent in the superpolyamides. By the application of a suitable force, however, the nylon filaments are drawn out to about four times their original length. During this cold-drawing operation, the diameter of each filament is reduced. The filaments have become highly oriented and have a different physical structure, as can be shown by x-ray diagrams. The orientation gives the filaments a high degree of elasticity and high tensile strength.

The cold-drawing of the nylon yarn, as well as sizing for the protection of the yarn during subsequent processing, is carried out on specially designed equipment. Twisting and packaging are effected on equipment familiar in the textile industry.

For the hosiery industry, the application of a knitting size is important, since knitting methods developed for silk depend on the natural gummy sericin coating on silk to protect the yarn. To prevent excessive snagging of the fine filaments during fabrication of the hosiery, nylon yarn must have a suitable knitting size applied. As in the case of silk sericin, the knitting size is removed from the finished product.

TABLE 3.1. PROPERTIES OF NYLON

Tenacity	4.5 to 8.0 gms./denier
Tensile strength	65,000 to 117,000 lbs./sq. in
Elongation, at break	20 to 12%
Specific gravity	1.14
Refractive index	1.52-1.58
Moisture regain, 65% R.H.	3.8%
Burning rate	Slow, melts
Melting temperature	482° F. (250° C.)
Resistance to heat	Damage starts at 446° F.
Resistance to abrasion	Excellent
Elastic recovery	Excellent
Effect of age	Slight
Effect of sunlight	Deteriorates on prolonged exposure
Effect of chemicals	Generally resistant
Effect of insects, fungi, mildews, etc....	Generally resistant
Color range	Extensive

PROPERTIES

Nylon yarns are manufactured in the denier range from 20 to 210 and in a range of filament denier from 1 to 630 or higher. The yarns can be made either bright or dull, the latter containing a delusterant. Tenacities range from 4.5 to 8 grams per denier, depending on the denier and type of yarn.

The elongation of the yarns can be varied from 12% (the practical minimum) to 100 or 200%. For special applications, the undrawn yarn, which has an elongation (through the equivalent of the drawing operation) of 400 or 500%, is available.

The various polyamides which make up the nylon family are crystalline in structure, although the individual crystals are too small to be seen even through the microscope. Nylon is known to be crystalline because of its x-ray diffraction pattern and because it has a rather sharp melting point, which, however, is different for the various kinds of nylon.

A most interesting physical property of nylon is that it can be cold drawn. This is an unusual property for crystalline materials, which are normally brittle when cold. If, however, a fiber which has been made under low tension is subjected to further tension, it can be drawn to from four to seven times its original length, depending upon the particular polyamide used.

Tensile Strength and Elongation. Nylon yarn can be manufactured so that it will have a relatively high or low tenacity, as desired. The lower the ultimate (breaking) elongation of nylon yarn, the higher will be the tenacity for any given type. Currently, types of yarn are being made which range from 4.5 to 8 grams per denier in tenacity with corresponding average elongation ranges of 20 to 12%. The tensile strength of these yarns ranges from 65,000 to 117,000 lbs. per sq. in.

The tenacity of thoroughly wet yarn is approximately 85% of its dry tenacity, ranging from 84 to 90% at 72% relative humidity, while the elongation of wet nylon is 5% to 30% greater than that of the dry at 72% relative humidity.

TYPICAL DATA FOR COMMERCIAL YARNS

<i>Bright Yarn</i>			<i>Average Values</i>	
<i>Denier</i>	<i>No. of filaments</i>	<i>Twist and direction</i>	<i>Tenacity (gms./den.)</i>	<i>Elongation (%)</i>
30	10	1Z	5.7	20
40	13	1Z	4.7	18.5
60	20	1Z	4.8	20
210	68	1Z	6.4	15.5

Chemical Resistance. Nylon flake or yarn is substantially inert to virtually all organic acids, carbon bisulfide, halogenated hydrocarbons (carbon tetrachloride, trichloroethylene), alkalis, soaps, gasoline, benzene, benzine, aldehydes, ketones, and alcohols. The outstanding exceptions are formic and carbolic acids, which are solvents for nylon. Other solvents are meta-cresol, cresylic acid, and xylol at 77° F. (25° C.).

Oxidizing agents and mineral acids, such as hydrochloric and sulfuric, cause nylon yarn to lose strength. Boiling in 5% hydrochloric acid makes it brittle and ultimately causes disintegration. Approximately 16% of the yarn strength is lost after immersion in 1 N hydrochloric acid or sulfuric acid for 10 minutes, or in 1/10 N acid for three days, at room temperature. Sodium hydroxide (10%) at 185° F. (85° C.) for 16 hours caused no degradation.

Cold concentrated nitric acid rapidly decomposes nylon. It is soluble in concentrated hydrochloric and sulfuric acids, and hot glacial acetic acid.

Abrasion Resistance. The yarn has a high resistance to abrasion. It is claimed that all-nylon hose have consistently shown two to two and one-half times the wear life of comparable gauges and weight of all-silk, and nylon used as reinforcing thread in the toe and heel gives superior wear to silk, rayon, or cotton in the foot areas. This resistance is attributed to its inherent tough-

ness, natural pliability, and ability to undergo a high degree of flexing without breakdown. The smooth filament surfaces do not readily create friction when rubbed against themselves or other surfaces.

It is also claimed that nylon bristles have lasted from three to four times as long as natural bristles in tooth brushes and in bottle-washing machines. A nylon "furnisher brush" in the textile printing industry was still in active service after a year, while natural bristles in some cases lasted only a week. Other brush applications showing unusual wear resistance were in sewage disposal plants, vacuum cleaners, dairy plants, electroplating and porcelain enamel equipment.

Specific Gravity. Nylon is lighter than other common fibers, as shown by the following tabulation:

<i>Fiber</i>	<i>Specific Gravity</i>
Nylon	1.14
Silk (raw)	1.30-1.37
Silk (boiled off)	1.25
Wool	1.32
Cotton	1.54
Rayon, viscose, cupra	1.52
Rayon, acetate	1.32
Ramie	1.52
Flax	1.50

In view of its low density, it might be assumed that nylon yarn would be bulkier and would give more coverage than any other common textile fiber for thread of a given weight. This, however, is not true in most cases for the following reasons: The thread is extremely compact, each individual filament being uniformly circular in cross section and free from surface irregularities. (In this respect, it is similar to a glass rod.) Nylon is comparatively translucent, particularly on the low twist bright yarn form. The result is greater sheerness than silk hose of comparable gauge and weight.

Nylon has an even greater advantage in weight saving when compared with non-textile materials. For example, when nylon wire (specific gravity 1.14) is substituted for copper wire (specific gravity 8.9) as in industrial filter screening, equal weights of these two materials will result in a much greater yardage of finished nylon screening. This helps to offset the higher cost of nylon per pound.

Elastic Recovery. This is the ability of a material to regain its original dimensions after being stretched. The length of time required for the yarn to recover its original length is important. Without elastic recovery, it is not possible to produce fabrics which will maintain their original shape or conform to specific contours of the body. The cling or fit of nylon and silk hose results from the inherent elastic recovery of the fibers.

Elastic Recovery of Silk and Nylon

(a) Recovery against no load; stretch for 100 seconds; recovery within 60 seconds.

Stretch %	Elastic Recovery (%)	
	Silk	Nylon
2		100
4	76	100
8	56	100
16	47	91

(b) Recovery against load of 0.25 gms./den.; stretch for 30 seconds; recovery within 60 seconds.

Stretch %	Elastic Recovery (%)	
	Silk	Nylon
1	82	88
2	71	63
4	59	73

Delayed Recovery. When nylon yarn is allowed to relax against no load after it has been held under tension for several days, it does not immediately return to its original length, but creeps back slowly. However, it recovers almost instantly about 50% of the stretch imparted; after 24 hours there is 85% recovery, and after approximately two weeks, complete recovery (relative humidity, 72%). The delayed recovery should be considered a part of the total residual shrinkage. When testing yarn for percentage residual shrinkage, the original length of the sample should be measured within 5 minutes; otherwise, some recovery will take place, and the results will be in error by the unknown amount of recovery which takes place before the original measurement.

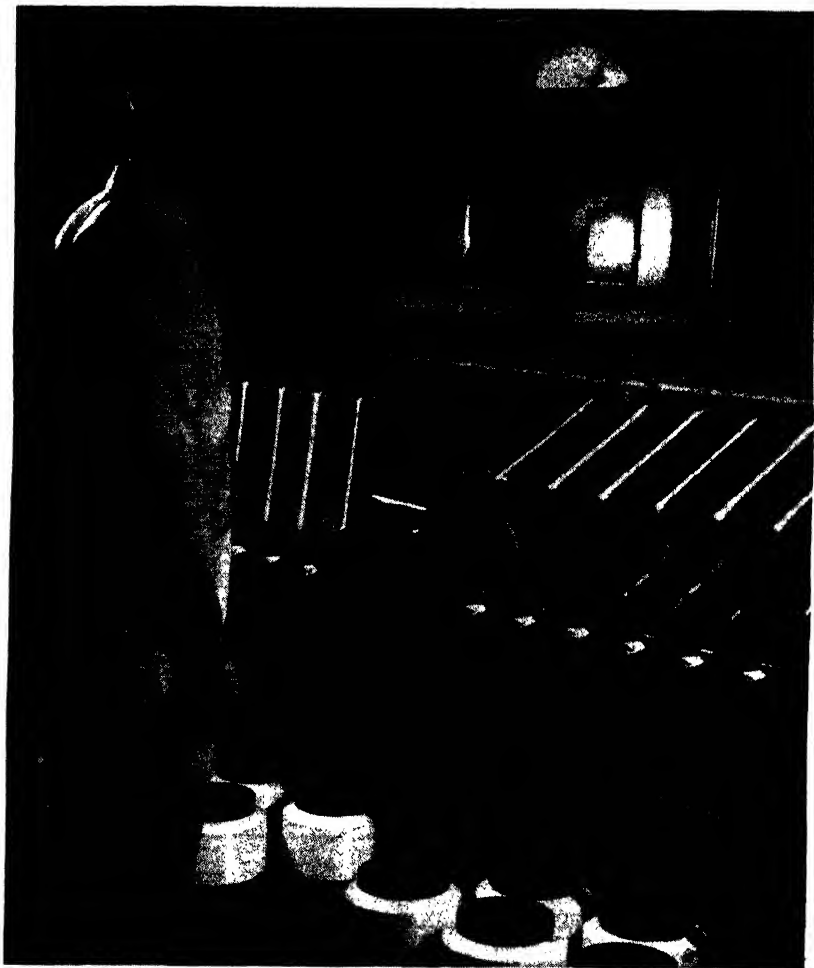
Stretchability. Unsized nylon yarn requires only from one fourth to one third as much tension for a given amount of stretch as silk, and less tension than wool or cotton.

*Comparative Tensions Necessary to Stretch the Common
Fibers 1%*

	<i>Gms./denier</i>
Unshrunk nylon	0.25
Shrunk nylon	0.10-0.15
Silk	0.75-1.16
Wool	0.32
Cotton	0.50
Glass yarn	2.75
Rayon, acetate	0.40
Rayon, viscose	0.70
Rayon, cuprammonium, and Ramie	0.90

It becomes easier to stretch nylon as the relative humidity rises. This is illustrated by the following table showing the tension required to stretch unsized nylon 1% at varying humidities:

<i>Relative Humidity (%)</i>	<i>Tension (gms./denier)</i>
0	0.48
50	0.31
100	0.116



Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 14. Nylon yarn is checked for weight. Samples of uniform length are taken from bobbins that come from the spinning machine and weighed to check the denier of the yarn.

Thread tension should be as uniform as possible in order not to introduce large variations in the amount of stretch. Nylon should be handled as if it were a rubber yarn. Although it possesses elasticity, like rubber, it does not recover or snap back after release of tension as quickly as rubber. Like rubber, it constantly tries to return to its original length when held under stretched conditions and therefore exerts appreciable contracting force. This is sufficient to crush partially the cores of cones and the maple barrels of bobbins, around which it is wound.

Flammability. Nylon yarn is more resistant to burning than silk, rayon and cotton. The undyed, finish-free yarn melts at a temperature of approximately 482° F. (250° C.) when a flame is applied, but as soon as the flame is removed, the melt hardens with little tendency for further burning. Undyed, unsized nylon yarn may be considered flameproof, since it does not support spread of the flame after the igniting source has been removed. In this respect, cotton, paper and wood are distinctly different.

If flammable oils or finishes are present on the fiber, there is, of course, a possibility that the resulting treated yarn will support combustion. Pigments and dyes may have the same effect.

Heat Resistance and Related Properties. Average "specific heat" of nylon between 68° F. (20° C.) and 482° F. (250° C.) is 0.555 calories per gram per degree Centigrade.¹ Heat of fusion is 22 calories per gram.

RESISTANCE TO DETERIORATION FROM HEAT

<i>Temperature</i>	<i>Medium</i>	<i>Storage conditions</i>	<i>Change in tenacity</i>
149° F. (65° C.)	Air	4 months (in dark)	5% loss
149° F. (65° C.)	Air	12 months (in dark)	20% loss
212° F. (100° C.)	Steam	6 days	Appreciable
392° F. (200° C.)	} Oxygen-free atmosphere (Nitrogen)	3 hours	None
437° F. (225° C.)		1 to 3 hours	Some decrease
473° F. (245° C.)		1 to 3 hours	Considerable loss

¹ "Physical-Chemical Properties and Processing of Nylon Textiles," E. I. du Pont de Nemours & Co., Inc., Nylon Div., Wilmington, Del.

Ironing at temperatures up to 356° F. (180° C.) has no effect on tensile strength, but sticking begins at this temperature. At 275° F. (135° C.) unset creases are removed. At 446° F. (230° C.) damage starts. Important factors to be considered in connection with ironing are the pressure applied, the time of contact of iron with surface of fabric, and the amount of moisture present in the fabric or in covering cloth.

Color changes of undyed fabrics after heating for 5 hours at 302° F. (150° C.) in dry air were as follows:

<i>Fabric</i>	<i>Color Change</i>
Silk	Brown
Wool	Yellow
Nylon	Light Yellow
Rayon, viscose and acetate ...	Very light yellow
Cotton	Very slight yellowing—barely noticeable

Standard and high tenacity yarns show no loss in tenacity and only slight decrease in elongation at a temperature —112° F. (—80°C.). Nylon rope showed no loss in strength when conditioned at —40° F. (—40°C.) for 6 hours and retained its original strength upon being reconditioned at normal temperature.

Resistance to Insect and Bacteriological Attacks. Tests indicate that nylon is subject to damage by some insects. *Clothes moths* cut their way out of scoured nylon cloth when trapped or imprisoned in the folds causing moderate damage. Neither the larvae nor the moths appear to eat nylon for food as they do in the case of wool. *Cockroaches* cause little or no damage. *Black carpet beetles*, *firebrats*, and certain varieties of *ants* cut their way out of nylon and silk fabric, if imprisoned.

Undyed, unfinished nylon yarns and fabrics have been found to be highly resistant to molds and other microorganisms. Fabrics exposed to soil burial tests for 21 days retained from 95-99% of their original strength and, after being rinsed in cold water, were found not to be discolored. The use of certain finishes on

nylon fabric might induce or support mold growth, without, however, appreciably affecting the strength of the fabric. Cotton fabrics, exposed under identical conditions, were destroyed.

Nylon fishing lines, waterproofed and nonwaterproofed, when exposed to fresh and salt water intermittently for a period of 6 months, lost only about 20% of original tensile strength. The waterproofed line accumulated during this period a 4 to 5 inch growth of marine moss, which was apparently feeding on the waterproofing material, as the nonwaterproofed line was not affected.

Effect of Light. Like other textile fibers, nylon yarn is subject to degradation on exposure to sunlight. The degree to which it is affected depends upon the type of nylon, whether it is bright or pigmented semi-dull, the thickness of the yarn, etc. It depends also on such external factors as the temperature, humidity, and season when exposed, and, of course, the duration of exposure.

Both bright and pigmented semi-dull nylon yarns were found to be superior to silk in resistance to deterioration under identical conditions of unprotected exposure 45° south for 14 days in Florida sunlight. The samples were given a thorough scour prior to exposure. Bright nylon is equivalent to either carded or combed cotton under the same exposure conditions.

A similar test made in Wilmington, Del., on unprotected samples exposed to direct sunlight 45° south for 16 weeks gave the following results:

<i>Type of Yarn</i>	<i>Average Per Cent Loss</i>	
	<i>Tenacity</i>	<i>Elongation</i>
Nylon, pigmented semi-dull	50	60
Nylon, bright	23	25
Silk	85	82
Linen	23	24
Glass yarn	37	0
Rayon, high tenacity viscose	20	21
Cotton	18	25

Unfinished samples of semi-dull nylon stored in the dark at room temperature showed no loss in strength after 9 months. Only a 2% loss in strength was shown by bright nylon stored in the dark at 149° F. (65° C.) for 16 weeks. Hosiery fabric from semi-dull nylon stored for 2½ years in a closet at room temperature showed no apparent loss in strength. Curtains of nylon hung in office windows facing northwest showed no evidence of deterioration at the end of a year.

Tests on ropes showed that comparable samples of nylon and Manila lost strength at about the same rate. However, nylon rope retained its initial advantage in strength over Manila rope at the end of a year of outdoor exposure.

Moisture Regain. The degree of moisture regain for nylon at any given relative humidity is considerably less than that for other textile fibers such as silk, cotton, wool, viscose rayon, or acetate rayon. For example, the moisture regain of nylon at 65% relative humidity is approximately 3.8%. This compares with 11% for silk, 7.5% for cotton, 11% for mercerized cotton, 16% for wool, 12% for viscose rayon, 6% for acetate rayon and 8% for linen.

The following table summarizes the average moisture regain of nylon yarn based on its weight in the dry state, at a temperature of 75° F. (24° C.). under various conditions of relative humidity:

<i>Relative Humidity</i> (%)	<i>Moisture Regain</i> (dry basis) (%)
10	1.1
20	1.4
30	1.7
40	2.3
50	2.8
60	3.4
70	4.1
80	5.0
90	5.7
97	6.2

The time required for unsized nylon fabric, either saturated at 100% relative humidity or essentially dry, to reach equilibrium at 72% relative humidity is approximately 20 minutes. This compares with 60-85 minutes for 450 meter skeins.

The low moisture regain of nylon as compared with rayon, silk or cotton makes the yarn more susceptible to accumulation



Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 15. A fan-like pattern of twisted nylon yarn feeds into the tire cord loom and weaver of a New Bedford, Mass., mill.

of static electricity. Therefore, it is important that relative humidity be maintained at as high a level as consistent with satisfactory performance of the manufacturing operation involved.

Shrinkage and Swelling. Fully shrunk nylon yarn gains in length when wet. Depending upon the degree of previous relaxation and removal of residual shrinkage, the wet length varies from

about a 3% gain to an actual loss in length as compared with dry nylon.

Sized, oiled and twistset* yarn showed the following degrees of shrinkage:

<i>Treatment</i>	<i>Yarn Shrinkage † (%)</i>
25° C., in water, for 3 minutes	0
50° C., in water, for 3 minutes	0.2
75° C., in water, for 3 minutes	0.5
100° C., in water, for 3 minutes	2.8
100° C., in steam, for 3 minutes	0.2
100° C., in steam, for 10 minutes	0.5
100° C., in steam, for 30 minutes	1.4
120° C., in steam, for 3 minutes	2.4
120° C., in steam, for 10 minutes	2.5

† Shrinkage of twistset yarn is dependent on the tension used in winding the packages prior to twistsetting.

The data indicate that boiling water is more effective than steam for shrinking nylon yarn at normal atmospheric pressure.

Water, glycerine, and sodium hydroxide (10% solution) caused no lateral swelling of nylon fibers at room temperature. Boiling with 10% Glauber's salt results in 3% swelling. The yarn immersed in 5% cresylic acid solution for 5 to 10 minutes at 122° F. (50° C.) shrank to about one half of its original length.

Optical Properties. Ordinarily, nylon in the massive state is opaque, but sheets 0.25 in. thick or less are somewhat translucent. Films can be made quite transparent by special processing.

Oriented nylon yarn is birefringent (doubly-refractive). Its refractive indices are $\eta_a = 1.52$ and $\eta_\gamma = 1.58$.

Electrical Properties. Dry nylon of a type suitable for textile yarns is a very good insulator, having a volume resistivity of 4×10^{14} ohms per centimeter (at 18% relative humidity). When

* Twistsetting conditions—wet bulb 160° F., dry bulb 170° F., relative humidity 75%, time 1.5 hours.

saturated with water, its electrical resistance is lower (about 5×10^9 ohms per centimeter).

Because of its good insulating properties and high abrasion resistance, the use of nylon coatings is indicated as insulation for wires in various types of electrical equipment. For this purpose the wire is not simply wrapped with nylon yarn, but is encased in a continuous film applied from molten nylon polymer. Nylon monofilament also has been used as insulation in coverings for electrical wires.

Toxicological Properties. Before nylon was introduced, tests were conducted at Haskell Laboratory of Industrial Toxicology (Medical Division of the Du Pont Company) on undyed and unfinished nylon, using as a control, rayon and natural degummed silk. There were no greater number of positive reactions from nylon than from the control fabrics. Based on these and other toxicological studies, it was demonstrated that the use of nylon alone involved no greater hazard than that of the control fibers.

It is claimed that nylon is non-toxic and therefore non-irritating to the skin. Employees of the Du Pont Company who have been in daily contact with the material have shown no ill effects. Moreover, nylon has met the rigid suture requirements of the medical profession and is being used successfully in surgical work. Cases of so-called "nylon dermatitis," or "an allergy to nylon," are attributed to contact with finishing materials. These claims are confirmed by Dr. Louis Schwartz, in charge of dermatoses investigations for the United States Public Health Service, Bethesda, Md.²

Dyeing. The methods of dyeing nylon are somewhat similar to those used for other fibers. Nylon has an affinity for a wider range of dyestuffs than have other common fibers, but it does not absorb the dyes very well. In general, the dyed fabrics are lacking in fastness to sunlight or to washing. Direct, acid, acetate

² "An Outbreak of Dermatitis from New Resin Fabric Finishes," *The Journal of American Medical Association*, Vol. 115, September 14, 1940, pp. 906-911.

and other classes of dyestuffs will color nylon, although it has a low receptivity for the acid, direct and vat dyes.

Acetate dyestuffs are usually preferred for nylon because of their better uniformity of dyeing compared with the other types. They have also been found to exhaust better, but give poorer light-fastness than the neutral dyeing acid colors which are usually employed for silk or wool. The light-fastness of the acetate colors on nylon is satisfactory for such uses as hosiery. Where the best possible light-fastness is desired, neutral dyeing acid colors may be preferred.

During the dyeing processes, nylon fabric should either be held smooth or else be "set" before dyeing, in order to prevent the formation of wrinkles which would be quite difficult to remove later. For example, a jig holds the fabric smooth during scouring and dyeing. For scouring and dyeing in rope form, it is generally necessary to pre-set it in a smooth condition, as on a roll in live steam at 10 or 15 pounds pressure, in order to prevent the formation of permanent wrinkles during dyeing. Even then, it may be necessary to hold the scouring and dyeing baths down to 170°-190° F. (77°-88°C.) for best results.

TABLE 3.2. AFFINITY FOR DYES OF CERTAIN FIBERS*

<i>Dyestuffs</i>	<i>Wool</i>	<i>Nylon</i>	<i>Acetate rayon</i>	<i>Viscose rayon</i>
Acid wool	All	All	Very few	None
Mordant	All	All †	Some	None
Metal containing	All	All	None	None
Direct cotton	Some	Some	None	All
Dispersed (acetate rayon) ...	None	All	All	None
Solacet	All	All	All	None
Vat	All	Some †	Some †	All
Azoic	Some †	Some †	Some †	All
Sulfur	Not used	Few	Not used	All
Basic	All	Some	All	All

* Source: "Nylon Yarn and Its Possibilities," G. Loasby, British Nylon Spinners, Ltd., *Rayon Textile Monthly*, December 1943.

† Special methods of application are necessary.

Vat dyes such as "Ponsol" or "Sulfanthrene" in general have very poor affinity for the standard type of nylon yarn. Sulfur colors (Sulfogene) also have poor affinity for nylon.

Mixtures of nylon with rayon or silk can be fairly satisfactorily dyed by the proper selection of direct, acid, and acetate dyestuffs.

APPLICATIONS

The great bulk of prewar output of nylon went into women's hosiery and this will undoubtedly continue to be the most important market for many years. Upon completion of its projected nylon expansion program, the Du Pont Company will be in a position to deliver 23 million lbs. of hosiery yarn per year. This would be enough to make about 450 million pairs of women's stockings. One pound of nylon yarn makes 20 pairs of stockings.

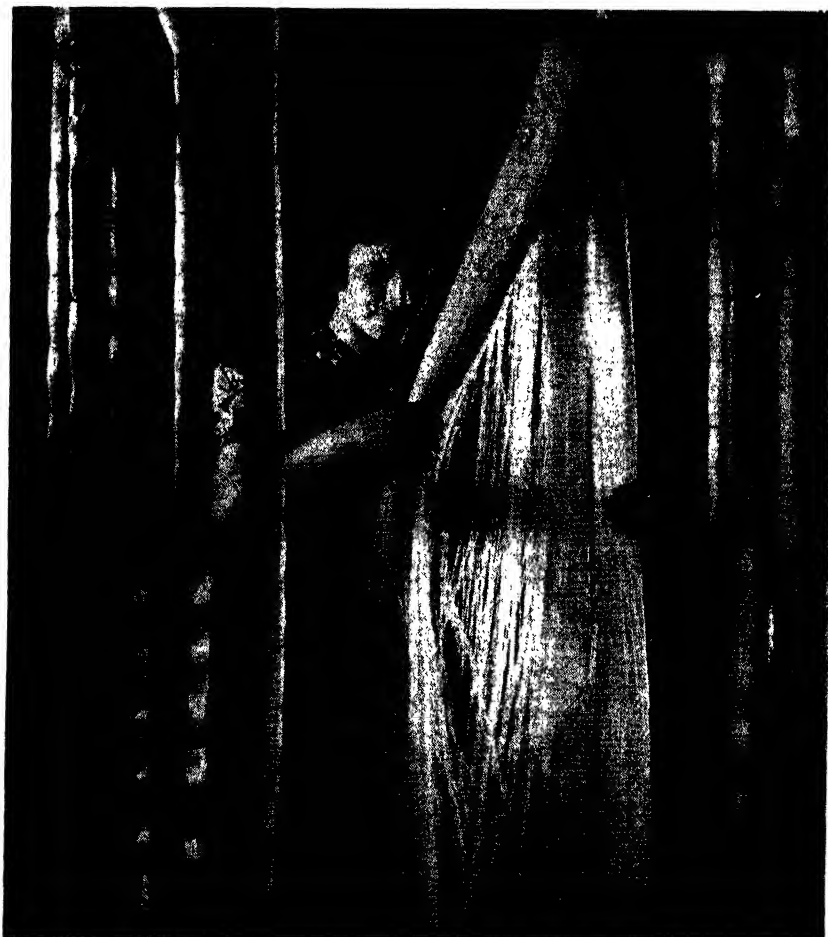
In addition, nylon yarn was used on a small scale in a variety of other products such as men's socks, neckties, women's knitted and woven underwear, sheer fabrics, sewing thread and fish lines.

One of the biggest uses for the monofilament was in bristles for brushes. According to the Du Pont Company, nylon was used in 90% of the better quality toothbrushes before the war, and 50% of the hair brushes. More than 20 different types of industrial brushes, ranging from textile-printing and bottle-washing to sewerage cleaning and electroplating, were bristled with nylon.

Nylon monofilament was used also in strings for tennis and badminton rackets, fishing leaders, and surgical sutures, as well as for insulation in coverings for electrical wires.

During the war, the use of nylon for civilian purposes ceased, and the entire output was devoted to wartime needs. Probably the most important of its military applications was for parachutes, where it served to replace silk. It was used also for such purposes as tow lines to pull gliders, climbing ropes for mountain troops, and shoe laces to resist deterioration in the tropics. In addition, it was used on a limited scale in large airplane tires.

It is too early as yet to say just how wide the field of use for nylon will be, but it has been suggested for a large number of



Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 16. Inspection of a hank of finished nylon ready to be cut into bristle lengths for use in tooth, hair and industrial brushes.

applications. These include: laces, nets, and marquisettes; sheer fabrics for dresses, blouses, and infants' wear; heavier fabrics for hatbands and blanket bindings; feather-weight fabrics—resin-

coated for raincoats, golf jackets, and other sportswear; dresses with permanent pleats; scuff-proof fabrics for women's shoes; wrinkle-resistant fabrics for men's shirts and suits; shower curtains; window curtains that retain their shape without being dried on stretcher frames; and draperies.

Other possible uses include: pile fabrics, such as velvet, plush, mohair, where the inherent crush resistance of nylon gives it a distinct advantage; automobile upholstery fabrics; slip covers; bathing suits; light-weight tents for camping; rust-proof and non-staining window screens; and theatrical wigs.

Industrial applications include woven fabrics for filters and bolting cloth.

TABLE 3.3. ESTABLISHED APPLICATIONS OF NYLON

Hosiery	Racket strings
Women's knitted and woven underwear	Parachute safety belts, straps, and cords
Sheer fabrics	Parachute fabrics
Sewing thread	Airplane tire cords
Surgical sutures	Glider towropes
Bead cords	Tapered brush bristles
Brush bristles	Mosquito netting and screening
Fishing lines and leaders	Hammocks
Men's socks	Shoe laces
Neckties	Plasma filters
Insulation in coverings for electrical wires	Tents
	Ponchos

NYLON STAPLE FIBER

Before the war, the Du Pont Company did some experimental work on nylon staple, but this work was interrupted by the war. Also, a number of mills took the nylon waste from the various textile operations and made this into spun yarns. From these yarns a number of woven and knitted wool-like garments including sweaters, socks, undergarments, and fleece coats were manufactured.

Nylon staple is said to have certain definite advantages. For instance, it contributes to wear resistance as measured by abrasion resistance tests. It is claimed that from 10 to 20% of nylon in overcoat fabric will add substantially more than this proportion to the life of the garment. The same thing is true when nylon staple is blended with wool in pile fabric such as a carpet or rug.

ELASTIC NYLON

Development of elastic nylon was announced by the Du Pont Company in early 1946.

Textile fibers made from certain of these new nylons, technically known as N-substituted polyamides, have elastic properties approaching those of rubber, and can be varied over a wide range, depending upon the molecular structure of the compound. One type, isobutyl 610, can be stretched 250 to 400%, in comparison with 600 to 1100% for rubber. The elastic recovery of this nylon was of the order of 95 to 99%, in comparison with 100% for rubber. Nylon yarn of the type now used in hosiery has an elongation of only 15 to 25%.

The "elastic modulus" of the N-substituted polyamide (the force required to stretch it 100%) is about 20 times that of a corresponding rubber fiber, while the tensile strength of the elastic nylon is about 5 times as great.

At the time of the announcement, the new type of nylon was not in commercial production.

PRICES

If we consider only its physical characteristics, we could easily forecast a future for nylon occupying as important a place in the textile industry as that now held by rayon. However, the price too must be considered, for no matter how excellent a fiber's properties may be, its use would be limited if the cost were too high relative to other fibers.

When nylon yarns were first made available for hosiery in 1940, they were priced at over \$4.00 per pound, which was competitive with the best grades of silk. Since then, nylon yarn prices have

been reduced several times, although they are still considerably higher than the prices of cotton, wool, and rayon.

In the 18 months prior to the war, the Du Pont Company reduced nylon yarn prices on two different occasions, and during the war years, it reduced the prices on Government business four times.

It is reasonable to expect that with further technical improvements and increased manufacturing efficiency the downward trend in nylon prices will continue. This, however, is based on the assumption that increased efficiency will not be wholly offset by inflationary trends.

It is considered unlikely that the price of nylon will ever be as low as that of rayon, since the basic materials involved in its production are more expensive.

Thus far, nylon has been used largely to replace silk in products such as stockings, parachutes, thread, and fishlines, where these fibers sold at about the same prices. To replace cotton, wool, or rayon in a given use, nylon would have to possess advantages sufficient, in the estimation of the consumer, to outweigh its higher price. It is too early to make any definite forecasts on this point, since nylon, thus far, has gone into only a limited number of uses.

However, it seems quite conservative to predict that nylon will be used in the next few years in at least as large volume as was silk in the years preceding the war. This would be from 50,000,000 lbs. to 75,000,000 lbs. annually.

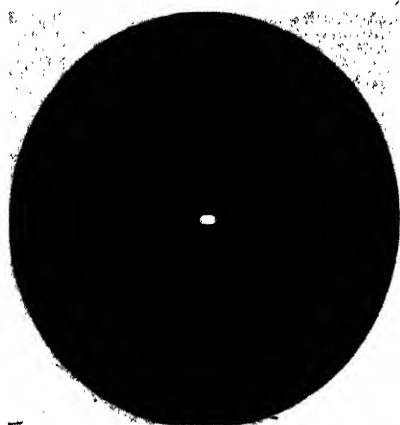
TABLE 3.4. NYLON YARN PRICES*

<i>Denier</i>	<i>Filament</i>	<i>Type</i>	<i>Put up</i>	<i>Price/pound</i>
30	10	200	Bobbins	\$2.75
40	13	200	Bobbins	2.25
70	23	200	Bobbins	1.75
70	34	300	Bobbins	1.90
105	34	300	Bobbins	1.80
210	68	300	Bobbins	1.75
210	34	300	Bobbins	1.60

* Effective September 1, 1945.

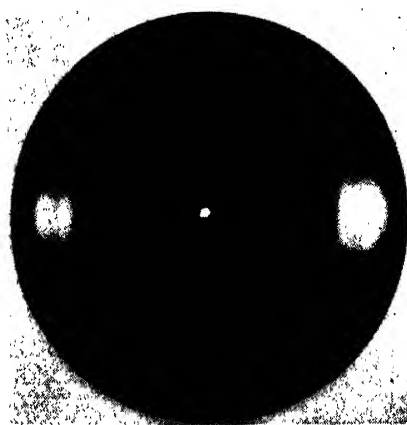
RESEARCH AND THE FUTURE OF NYLON

In appraising the future of nylon, too much emphasis cannot be placed on the fact that it has the vast resources of the Du Pont Company behind it and that it will continue to benefit from the well-organized research for which that company has long been known. Such research should have two important long-range effects: (1) the development of new and improved types of nylon,



Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 17. X-ray pattern of unoriented nylon filaments.



Courtesy E. I. du Pont de Nemours & Co., Inc.

FIG. 18. X-ray pattern of oriented nylon filaments.

and (2) gradual reduction in the cost of manufacture through utilization of cheaper raw materials and processes.

For example, an improved type of nylon was recently developed which is particularly useful in making brush bristles. Incorporation of phenol-formaldehyde resin in the nylon mass gives a marked degree of stiffness and water resistance to the bristles. It is claimed that a further advantage is a reduction in cost of the material.

During the war, research efforts on nylon were directed toward the attainment of higher strength, as that property was then most important. After the war ended, however, the research em-

phasis was shifted to the dyeing of nylon toward which the Du Pont Company is now directing its attention.

There are thousands of types of nylon possible, since there are dozens of different dibasic acids, diamines, and amino-acids, as well as other compounds which can be used in making polyamides. For example, if there were only ten different dibasic acids and ten different diamines, it would be possible to make 100 different nylons. Actually, by interpolymerization of various dibasic acids, amino-acids, and diamines, many more types of nylon can be made. Thus, one dibasic acid could be made to react with two different diamines at the same time, and in varying proportions, or vice versa. Also, two or more different nylon polymers might be blended to give a composition different from the parent nylons. Therefore, an almost unlimited number of nylons are possible, with different melting points, solubilities, and other properties.

CHEMISTRY

The nylons are characterized by recurring amide groups as an integral part of their main polymer chain and hence are classified as polyamides. A general structural formula for the recurring groups in the nylon (polyamide) molecule can be symbolized as



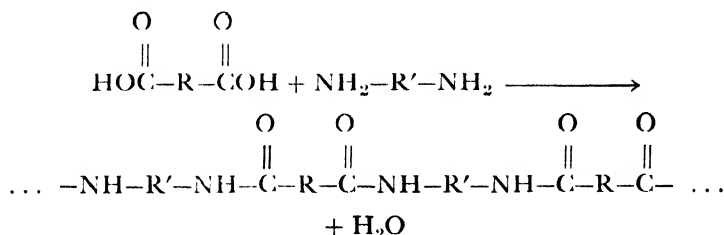
where R represents several $-\text{CH}_2-$ groups.

The polyamides are of two types: (1) those derived from polymerizable monoaminomonocarboxylic acids (e.g., 6-aminocaproic acid, $\text{NH}_2(\text{CH}_2)_5\text{COOH}$) or their amide-forming derivatives, and (2) those derived from the reaction of suitable diamines with suitable dicarboxylic acids or amide-forming derivatives of dibasic carboxylic acids.

The following are typical diamines and dibasic acids:

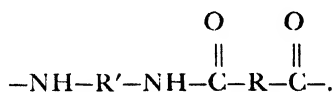
<i>Diamines</i>	<i>Dibasic Acids</i>
Decamethylenediamine	Azelaic acid
Octamethylenediamine	Suberic acid
Hexamethylenediamine	Sebacic acid
Pentamethylenediamine	Adipic acid
Tetramethylenediamine	

When a dibasic carboxylic acid and a diamine are heated together under suitable conditions for amide formation, the reaction proceeds in such a way as to yield a synthetic linear polyamide.



where R and R' are divalent hydrocarbon radicals.

The indicated formula represents nylon as being composed of long chains built up from a series of identical structural units as



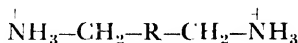
In the preparation of polyamides directly from the diamine and the dibasic acid as indicated above, it has been found advantageous to prepare and isolate the diamine-dicarboxylic acid salt and use it as an intermediate in nylon manufacture.

The first reaction which occurs, when a diamine of formula $\text{NH}_2-\text{CH}_2-\text{R}-\text{CH}_2-\text{NH}_2$ and a dicarboxylic acid of formula $\text{HOOC}-\text{CH}_2-\text{R}'-\text{CH}_2-\text{COOH}$ are mixed and brought into sufficiently intimate contact, is the formation of the diamine-dicarboxylic acid salt of formula

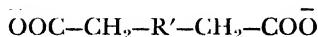


where R and R' represent several $-\text{CH}_2-$ groups.

These salts are crystalline solids having fairly definite melting points. They are relatively insoluble in acetone, ether and benzene, but are soluble in water and alcohol-water mixtures. The salts dissociate in water to give diammonium ions of formula

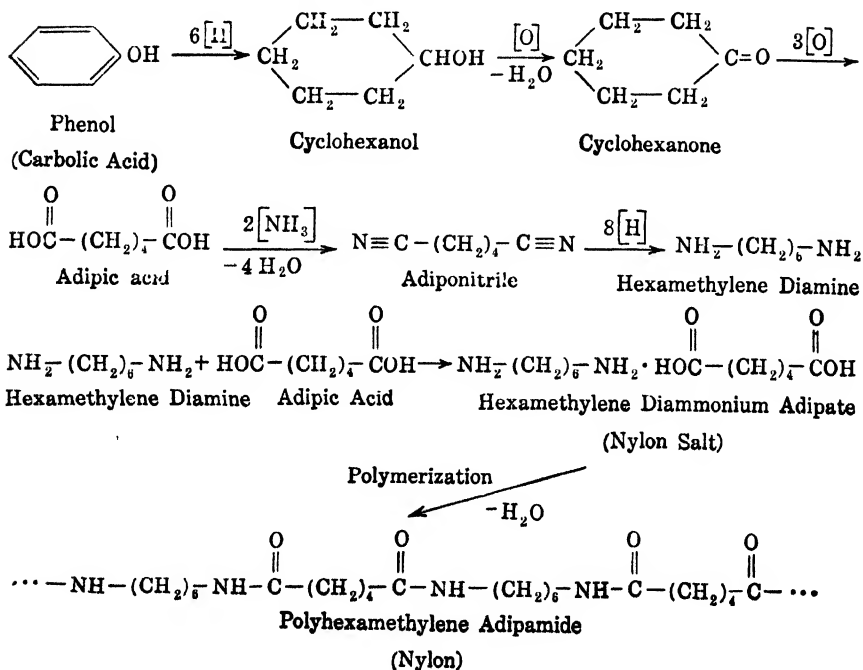


and dicarboxylate ions of formula



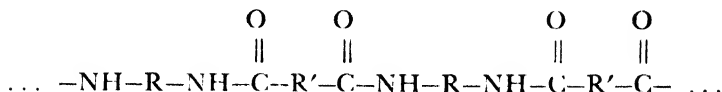
Since the tendency of these salts to dissociate into their components is relatively low, both the acid and amine are fixed. The salt is isolated and purified prior to its conversion into the polyamide.

Polyhexamethylene adipamide, the nylon produced commercially on the largest scale, is derived from the diamine, hexamethylene diamine and the dibasic acid, adipic acid. The production of these two basic materials is structurally outlined by the following chemical reactions:

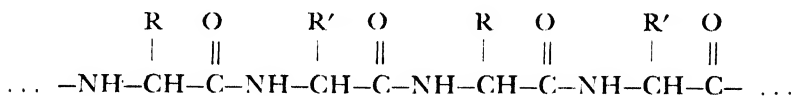


NYLON STRUCTURE COMPARED WITH NATURAL FIBERS

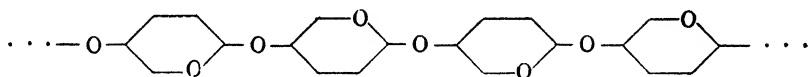
Structurally the nylons



are more closely related to the natural protein fibers, such as silk and wool, which also are polyamides—



than they are to the cellulosic fibers, such as cotton and flax, which are polyacetals—



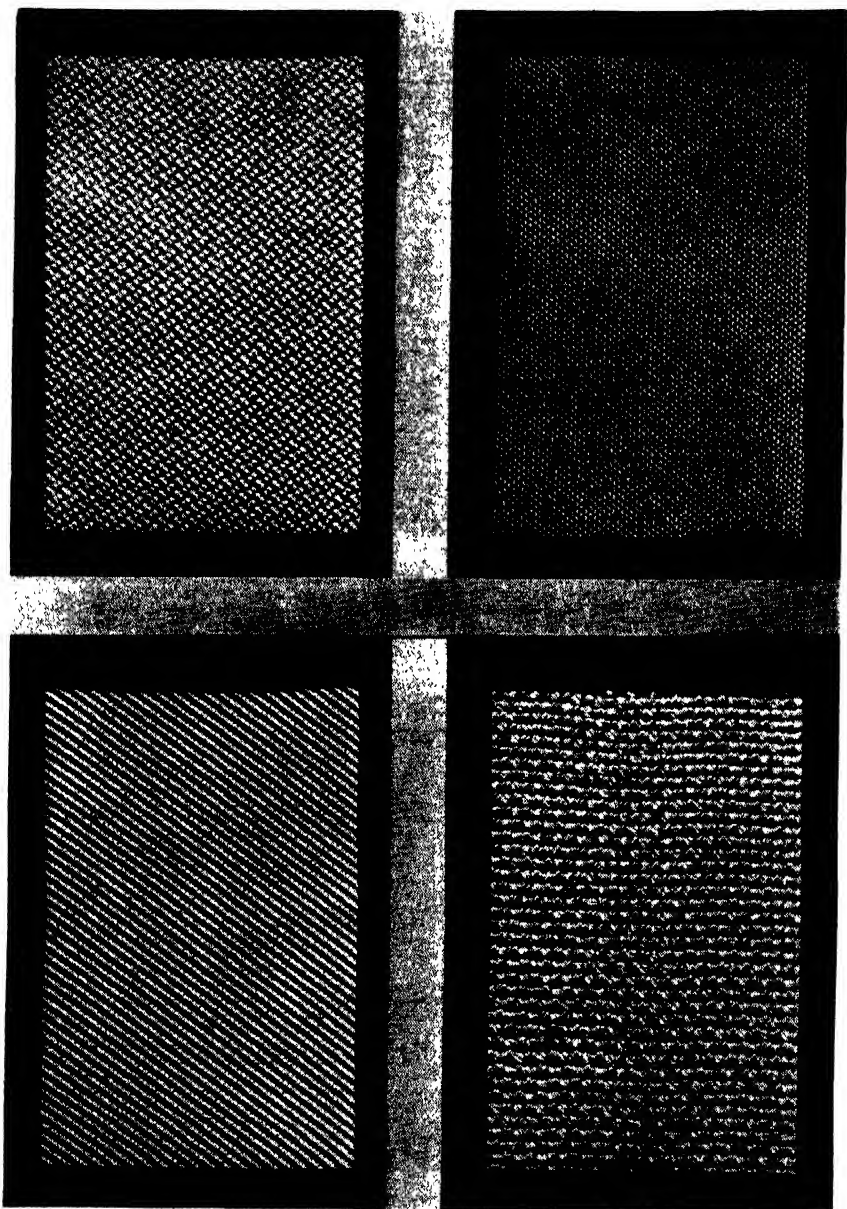
In the case of silk, R and R' represent principally the $-\text{CH}_3$ group. For wool, the structure is extremely complicated, with R and R' representing principally the alpha-amino acids such as cystine, glutamic acid, leucine, arginine, histidine, alanine, lysine, and glycine ($\text{NH}_2\text{CH}_2\text{COOH}$), which is the simplest.

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Courtesy Wellington Sears Company

FIG. 19. Filter fabrics of Vinyon. Its excellent chemical resistance has made it highly useful for this purpose.

CHAPTER IV

Vinyl Resin Fibers

SUMMARY

Up to the present, Vinyon, one of the first of the synthetic fibers, has had its most important use in industrial filter cloths. Its resistance to acids, alkalies, and other liquids and gases is outstanding. It also has been used to a limited extent in fish lines and nets, where its resistance to water is an advantage, and in shoe fabrics, gloves, upholstery, millinery cloth, and other textiles.

Vinyon has the decided disadvantage of shrinking at a temperature of 150° F., which precludes its use in garments and other textiles that are ironed at ordinary temperatures. Its thermoplasticity, however, is utilized in the manufacture of felts, where Vinyon cements together non-felting fibers, such as cotton. Its tensile strength when dry compares favorably with the high-strength rayon used for tire cord. Unlike rayon, it loses none of its strength when wet.

HISTORY AND DEVELOPMENT

In 1938, American Viscose Corporation commenced the production and sale of Vinyon, a yarn made from Vinylite under a non-exclusive license from Carbide and Carbon Chemicals Corporation. Its development resulted from extensive cooperative research programs carried out by Carbide and Carbon Chemicals Corporation, supplier of the resin, and American Viscose Corporation, spinner of the yarn.

The basic patent ¹ on Vinyon ² assigned to Carbide and Carbon Chemicals Corp. was applied for in 1937 and issued in 1939. It might be considered a classic for its clear description of the process for making the new yarn.

The following are the opening paragraphs of the patent:

The quest for a truly synthetic textile fiber has had few rivals in its intensity, and, through the past, in its conspicuous lack of success. It has been proposed to make textile fibers and filaments from many synthetically produced materials, but until now none of these has ever yielded a commercially usable product. The only commercially useful textile fibers at present, as in the beginning, are products of nature, supplemented more recently by those from chemically modified natural products, such as the esters and ethers of cellulose, and cellulose itself regenerated from its derivatives.

This invention makes possible a synthetic fiber of many unique and distinctive properties, including high true elasticity, flexibility, high strength and remarkable resistance, and it provides an easily producible product not originating in nature which equals and surpasses in many respects natural fibers and fibers made from modified products of nature. The synthetic fibers of this invention are formed of certain types of vinyl resins, and the invention includes methods of forming, treating and using the new fibers, all as more fully hereinafter described.

Vinyl resins have been proposed for use in forming textile fibers by nearly all who have had experience with them, and this was entirely to be expected, since these resins are products which are truly synthetic, as well as readily formable, inherently colorless, odorless, tasteless, and not readily inflammable. Nevertheless, in the twenty years and more since vinyl resins first were suggested for this purpose, useful or practical fibers have never been produced from any vinyl resin of these types.

MANUFACTURE

Regular Vinyon is a textile fiber made from an unplasticized vinyl resin which is a copolymer of vinyl chloride and vinyl acetate. The resin used in its manufacture contains 88 to 90% vinyl chloride and 12 to 10% vinyl acetate. The copolymer resin

¹ U. S. Patent 2,161,766 (June 6, 1939).

² Registered trade-mark of Carbide and Carbon Chemicals Corp.

(molecular weight around 20,000) is a white fluffy powder. It is dissolved in acetone to yield a heavy, viscous spinning dope containing about 25% by weight of the resin. This is filtered, deaerated, and spun downward in air through multiholed stainless-steel jets, just as is done in acetate spinning. The solvent, acetone, is removed by a current of warm air and recovered.

After being conditioned on the take-up bobbin, the yarn is stretched either directly or after being plied with one or more ends. This stretching operation is of great importance in producing a serviceable yarn having good strength, extensibility, elasticity, and resiliency. For high strength, the yarn is stretched several hundred per cent; for lower strengths, but greater softness and more extensibility, the stretching is correspondingly less.

Analysis by x-ray shows that stretching orients the molecules along the filament axis, whereas in the unstretched yarn the long-chain molecules of the copolymer lie at random. This molecular orientation is responsible for the remarkable increase in strength. Apparently, the frictional drag of one long molecule over another increases as the molecules become oriented.

After stretching, the yarn is set by heating, while under tension, to about 90°-100° C. (194°-212° F.). This treatment makes the yarn stable as to shrinkage up to at least 65° C. (150° F.), but when heated above this temperature, shrinkage of the yarn occurs with a corresponding reduction in tenacity and increase in elongation.

The filaments, as spun, are of a dumbbell shape in cross section, and are much larger than after stretching. This stretching, while reducing the area, does not alter the cross-sectional shape; nor does it cause any tendency toward brittleness. A yarn of 10 filaments may be only 8 denier in size. Although the filaments are finer than silk, their strength and elasticity are such that they can be processed, woven and knitted on standard equipment. For example, an 8-denier 10-filament yarn is strong enough to be knit on a regular-circular stocking machine.

Vinyon is produced in both the continuous filament and staple fiber forms. Where the staple fiber is used for its thermoplastic

property, the unstretched lustrous yarn is preferred. This yarn normally has a filament denier of 2.5. The stretched continuous-filament high-strength yarn has a filament denier of about 1 and is delustered by warm water during its manufacturing process.

Textile Processing. Vinyon yarn readily lends itself to the ordinary throwing operations. It is preferable to run the yarn under conditions of high relative humidity in order to eliminate static electricity.

The yarn has exceptionally good knitting properties. In tests conducted on hosiery, ribbing, and circular knitting machines, Vinyon yarn proved more adaptable than commercial rayons. This was indicated by the ease of securing much tighter stitch without thread rupture.

Vinyon yarn also serves well as filling and as warp supply in weaving. The yarn may be run while "surface-wetted," as its strength is the same when wet as when dry.

PROPERTIES

Perhaps the most distinctive characteristic of Vinyon is its unusually high resistance to chemicals.

It is exceptionally resistant to mineral acids and alkalis. It is not attacked at room temperature by 70% nitric acid, by aqua regia, by concentrated hydrochloric or hydrofluoric acids, by 30% sodium hydroxide, or 28% ammonium hydroxide. It is likewise resistant to salt solutions of all types, including cuprammonium solutions, etc. It is unaffected by alcohols, glycols, and aliphatic hydrocarbons (such as gasoline and mineral oils).

However, it is dissolved by ketones and is softened or partly dissolved by esters, certain halogenated hydrocarbons, ethers, certain amines, and by lower aromatic hydrocarbons.

Vinyon is extremely water-repellent, but it may be "surface-wetted" by use of commercial wetting-out agents. The yarn does not support combustion. It is not attacked by bacteria, molds or fungi and will not support their growth. Its stability to sunlight is said to be excellent.

Vinyon does not conduct electricity, and as water does not affect it, it is an excellent insulator. Its high insulating power is shown by the ease with which it develops and retains the static charge.

TABLE 4.1. TENACITY AND ELONGATION OF VINYON COMPARED WITH SILK AND RAYON*

Yarns	Dry 65% Relative Humidity		Wet	
	Tenacity (gms./den.)	Elongation (%)	Tenacity (gms./den.)	Elongation (%)
Silk, degummed	4.22	15.7	3.40	26.3
Viscose rayon	2.00	18	1.00	25
Acetate rayon	1.40	27	0.85	36
Vinyon, HST † (high stretched)	4.00	18	4.00	18
Vinyon, ST † (stretched)	2.30	25	2.30	25
Vinyon, UST † (unstretched) .	1.00	120	1.00	120

* Source: Carbide and Carbon Chemicals Corp.

† The tenacity may be controlled within a range of 1.00 to 4.00 grams per denier and the elongation corresponding from 120% to 18%, the higher strength corresponding to the lower extensibility and vice versa.

Unlike most other synthetic fibers, Vinyon has the same tensile strength in both wet and dry states. The tenacity may be controlled at will within a range of 1 to 4 grams per denier with corresponding elongations at the break of about 120 to 18%, respectively. Its flexing strength is excellent.

The vinyl resin filaments are definitely thermoplastic. When not under tension at elevated temperatures, unset filaments show a pronounced crimpage or shrinkage. The contraction in length is proportional to the change in temperature. Shrinkage is accompanied by a slight reduction in tenacity and an increase in elongation.

Set vinyl resin filaments (the type normally produced) do not shrink below the set temperature, which is usually 150° F. (65° C.). Up to this temperature the yarn may be heated without appreciable change in length. When heated above this tem-

perature, it shrinks, but such contraction is definitely lower than that of the unset yarn under similar conditions. The amount of shrinkage depends upon the temperature; for example, at 75° C. (167° F.) the shrinkage is about 12%. At 80° C. (176° F.) the individual filaments of the yarn shrink markedly and adhere to each other. At a temperature between 135° to 140° C. (275° to 284° F.) definite tackiness develops in the yarn.

The shrinkage characteristic of Vinyon yarn can be utilized in overcoming "laddering" in knitted goods and thread slippage in woven goods, as well as in improving certain crepe and tightly knitted or woven constructions. This can be effected by subjecting the fabric of the set or unset yarn either to elevated temperatures or to a solvent-nonsolvent bath at required temperatures and concentrations.

TABLE 4.2. PROPERTIES OF VINYON*

Tenacity, wet and dry:

Unstretched	0.7 to 1 gms./denier
Regular	2 to 2.8 gms./denier
High stretched	3.5 to 4 gms./denier

Tensile strength:

Regular and high stretched	35,000 to 69,000 lbs./sq. in.
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Elongation, at break:

Regular and high stretched	35 to 18%
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Elasticity

Comparable to silk

Flexural strength ...

High

Specific gravity

1.34 to 1.36

Water absorption:

(24 hrs. immersion at 25° C.)	0.05 to 0.15%
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Shrinking temperature

Above 65° C. (150° F.)

Softening temperature

75° to 80° C. (167° to 176° F.)

Inflammability

Does not support combustion

Effect of sunlight

None

Electrical properties

Non-conductor

Chemical resistance

Excellent

Bacteria and fungi resistance

Not attacked

* Source: Carbide and Carbon Chemicals Corp.; American Viscose Corp.

DYEING

The dyeing of Vinyon has presented a number of problems, because of its lack of affinity for most dyes and its low shrinking temperature (150° F.).

Vinyon is not readily permeable to water and cannot be satisfactorily dyed by the ordinary procedures used for dyeing cotton, wool, silk, and viscose rayon. When those methods of dyeing are attempted, the dye either does not penetrate the material and fails to take effect, or else when dyeing is effected, the color is not fast and washes out.

The acetate rayon dyes have been found to be most useful, but even with these only a limited number yielded deep and fast shades. By having present in the dyeing bath certain chemical "assistants" such as esters, amines, phenols, or open-chain ethers, the usefulness of the acetate rayon dyes can be extended. An ordinary amount of dyestuff can be used (e.g., 2%) which, in the presence of the assistant, such as *o*-hydroxydiphenyl, is satisfactorily exhausted. The choice of assistant is, however, quite important because it influences the fastness property of the dyestuff.

Recently, it was found that a type of azo dye has good affinity for Vinyon (British Patent 568,037). The dyeing of Vinyon, however, must still be considered as in the experimental stage.

APPLICATIONS

Thus far, the principal applications of Vinyon have been in the industrial field; it has been used only to a very limited extent in wearing apparel.

The largest single application of Vinyon has been for industrial filter cloth. Its unique chemical inertness, and the fact that it does not absorb moisture, swell, or lose its strength when wet, make it a most valuable filter cloth material. Among the materials being successfully filtered at the present time with fabrics made of Vinyon are dyestuffs, pigments, clays, pharmaceuticals, bleach liquors, lime sludges, electroplating solutions, concentrated caustic solutions, and strong mineral acid solutions.

The wear of Vinyon filter cloth in use arises from abrasion and other mechanical causes rather than from chemical deterioration. It can be easily cleaned by the use of acids, alkalies, or hydrocarbon solvents without any chemical damage to the cloth.

Perhaps the principal limitation to its use as a universal filter cloth material is its thermoplastic property. It shrinks when heated above 150° F. (65° C.). Below this temperature lies its field of usefulness.

Vinyon has also been used as packing material in pipe lines carrying hydrofluoric acid utilized in the manufacture of high-octane gasoline.

Because of its high wet strength, Vinyon makes excellent fish lines and nets. It resists the action of bacteria, molds, and mildew and is not attacked by insects. Such fish lines or nets do not need the usual copper naphthenate treatment, but can be left in damp places for a long time without rotting or deterioration.

The toughness and elasticity of high-strength fine-denier Vinyon yarns have adapted them for use in screen printing. The fabric maintains its firm, drum-like tension on the frame, wet or dry, and does not sag in use. It is particularly desirable for use in discharge printing, since it is not affected by concentrated caustic solutions. It does not absorb any of the dyestuffs during printing, and it is easily washed. The fabric will not be affected in any way if the screen is put away while wet. Nor will the fabric deteriorate when the screen is stored away for a long time.

Another application of fine high-strength Vinyon yarns has been in non-absorbing surgical sutures. Such sutures have been used for a number of years. Sterilization is effected in ethyl alcohol.

When Vinyon was first introduced, it was believed that it would have important applications in certain items of wearing apparel, but such expectations have not generally been realized. Vinyon was used commercially in women's gloves and shoes, but apparently did not take hold marketwise.

Vinyon gloves were brought out in 1941. Although they had good wearing and drying qualities, they were said to look cheap

and to feel heavy and fuzzy. They retailed at a dollar a pair, but were soon withdrawn from the market.

Vinyon shoes were introduced in the summer of 1941 at \$14.75 a pair. They weighed only 4 ounces each. An interesting feature of the shoes was that the yarn was knitted into a net and then fused. This illustrates that the shrinkage or thermal setting of Vinyon has definite advantages in certain applications. Thus, fabrics can be knit or woven, then thermally shrunk and set, in making fabrics not only for shoes, but also for hats and other items of apparel.

Vinyon staple fiber produced from unstretched filaments is particularly useful as a binding agent or stiffener for admixture with wool and cotton fibers. It is thermoplastic, and fusion or partial fusion of the fibers in such a mixture makes possible novel and desirable stiffening or binding effects. The staple fiber, in admixture with cotton and wool, makes possible the production of fabrics which retain a pressed fold and improves mercerizing and acid carbonizing. Staple fiber produced from stretched filaments lends high strength to the yarn produced from mixtures containing it.

PRODUCTION AND PRICE DATA

During the war period, the output of Vinyon was well under one million pounds a year. It went chiefly into industrial filter cloths.

The price of Vinyon in 1944 ranged from \$1.40 to \$1.80 a pound for continuous-filament yarn and from \$1.00 to \$1.15 a pound for coarse or fine staple fiber. Detailed prices as of 1945 are shown in Table 4.3.

VINYLLITE RESIN MONOFILAMENTS

In addition to their use for the production of Vinyon multifilament yarns, the vinyl chloride-vinyl acetate copolymer resins are employed for the production of monofilaments. In the latter case a melt extrusion technique is used in which the resin com-

pound is forced through suitable orifices at relatively high temperatures to form coarse filaments which are subsequently stretched and annealed.

TABLE 4.3. VINYON YARN PRICES (AS OF JULY, 1945) *

	<i>Price per pound</i>	<i>Package</i>
Vinyon ST (medium strength)		
250/216	\$1.35	Spools and cones
Vinyon HST (high strength)		
40/28	1.70	Spools and cones
80/56	1.65	Spools and cones
120/84	1.55	Spools and cones
160/112	1.45	Spools and cones
200/140	1.40	Spools and cones
Vinyon N-ST (medium strength)		
250/140	2.00	Spools and cones
Vinyon staple		
Fine (ST)	1.15	
Coarse (UST)	1.00	
Vinyon tow		
Coarse (UST)	1.10	Tubes

* Source: American Viscose Corp.

These monofilaments have the same chemical, water, and fungus resistances as the multifilament Vinyon yarns. They may be readily colored by the inclusion of suitable coloring materials in the extrusion compound. The monofilaments are characterized by high resiliency and excellent durability.

The physical properties of a representative sample of one type of Vinylyte resin monofilament are as follows:

Diameter	0.017 in.
Straight tensile strength	45,400 lbs./sq. in.
Knot tensile strength	22,600 lbs./sq. in.
Elongation	22%
Shrinkage at 60° C.	0.9%
65° C.	2.2%

For special applications where softness and ease of extensibility are required, suitable plasticizers may be added to the resin compound with a consequent reduction in tensile strength and increase in elongation.

Vinylite resin monofilaments have a wide range of potential applications. They may be used as bristles for nail, hair, and tooth brushes; for making insect screens, upholstery fabrics, ropes and many other products.

MONOFILAMENTS FROM MULTIFILAMENTS

An interesting new development involves the production of monofilaments from multifilaments. This is described in British Patent 560,535 taken out by American Viscose Corporation. The improved method for producing Vinylite resin monofilaments involves fusing a number of thermoplastic filaments associated in the form of a bundle. The circular cross-section monofilament is especially suitable for use in the manufacture of hosiery, tennis rackets, bristles, violin strings, artificial horsehair, etc.

VINYON ELASTIC YARN (VINYON E)

A stretchable vinyl resin yarn to replace rubber and latex for elastic tapes, webbing, and cord, was announced in 1943. It was manufactured by American Viscose Corporation from vinyl chloride-vinyl acetate resin produced by Carbide and Carbon Chemicals Corporation.

The yarn derives its elasticity from a special plasticizer added to the spinning dope. Vinyon E synthetic fiber is thus comparable to the elastic-type vinyl plastic, while Vinyon is comparable to the rigid plastic which contains no plasticizing agent.

Vinyon E is said to be the first synthetic fiber to have a marked degree of elasticity. It can be made with an elongation ranging from 150 to 400% of its original length.

Unlike latex products, which consist of extruded monofilaments, vinyl resin yarn is a true textile yarn containing a number of parallel filaments. This results in an improved "hand" to cloth woven from it and also greater flexibility. The yarn can be covered like latex or rubber products, or it can be used without covering for special purposes.

Vinyon E has less rapid elastic recovery after stretching than rubber yarn, but it has considerably greater fatigue life, as well as superior resistance to oxidation and acid perspiration.

The yarn withstands boiling in water for as long as 12 hours without damage, but continuous exposure to dry-cleaning solvents and soap solutions causes stiffening, since these tend to dissolve the plasticizer. Therefore, sulfated alcohol-type detergents are recommended for scouring, dyeing, or laundering.

Elastic properties of the yarn are retained between temperatures of 0° and 75° C. (32° and 167° F.). Below this range, the yarn tends to stiffen and becomes sluggish, while above it, it tends to deform permanently when stretched. In general, the elasticity increases as the temperature rises.

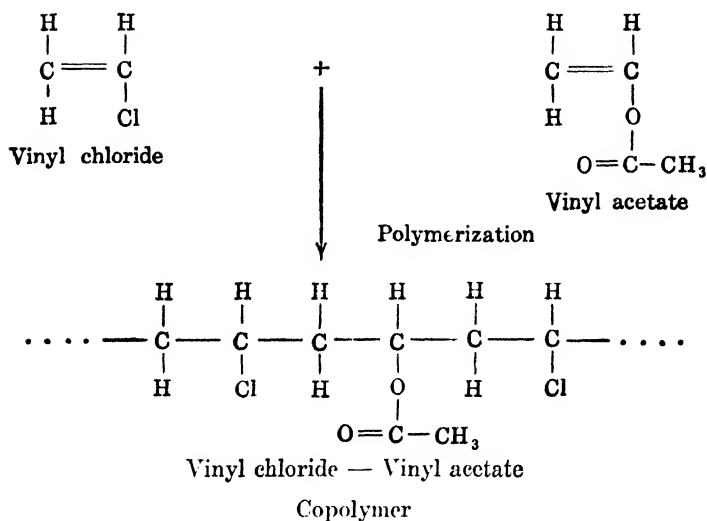
Use of the yarn was limited to military needs. Applications included knee braces and elastic tapes for metatarsal pads, elastic tapes for garments for the Women's Army Corps and elastic suspension cords for canopies of jungle hammocks for the Army. The yarn was also tested for use in heavy-duty suspenders for aviators' suits.

Production of this material was discontinued after the war, because of its limited uses and the availability of other elastic materials.

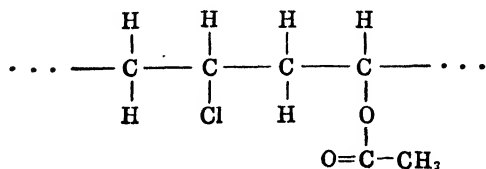
CHEMISTRY

The basic vinyl resins used for Vinyon are made by copolymerizing vinyl chloride and vinyl acetate. The copolymers contain (by weight) 88 to 90% vinyl chloride and 12 to 10% vinyl acetate. The molecular structure of these vinyl copolymers is

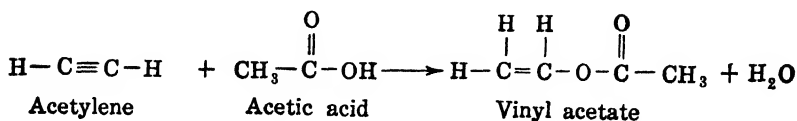
linear, in which the monomers react with one another at the double bond to give high-molecular weight molecules:



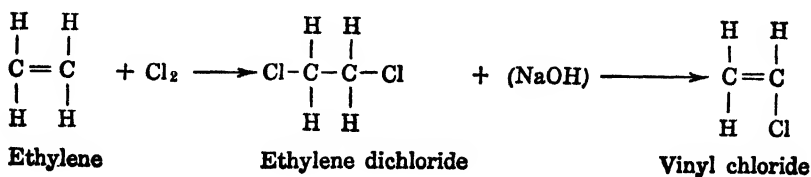
The unit structure for the vinyl chloride-vinyl acetate copolymer is—



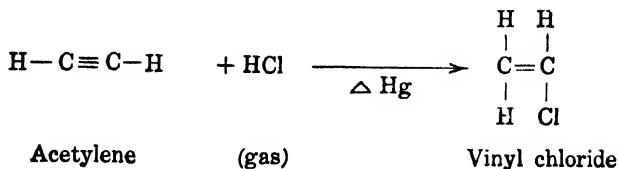
Vinyl acetate can be prepared from



Vinyl chloride can be made from



or by another method (British Patent 566,003) :



Doubling the molecular weight of a vinyl copolymer containing 90% by weight vinyl chloride and 10% vinyl acetate, from 20,000 to 40,000, raises the shrinkage temperature range by only about 5° C. (9° F.). The high-molecular weight copolymer is insoluble in acetone, chloroform, and similar solvents in which the resin of lower molecular weight is soluble.

REFERENCES

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6. "Vinyon Synthetic Fiber," Am. Viscose Corp.
7. "Vinyon as a Plastic Fiber," H. E. Shearer, *Rayon Textile Monthly*, September 1944, p. 69.
8. "Vinyon Elastic Yarn," *Bakelite Review*, Bakelite Corp., New York. July 1943.



Courtesy The Dow Chemical Company

FIG. 20. Saran monofilaments, spooled and cut into short lengths.

CHAPTER V

Vinylidene Chloride Fibers

(Saran and Velon)

SUMMARY

Vinylidene chloride resin, a basic material for making plastics and filaments, is produced by The Dow Chemical Company under the trade name Saran and sold to other companies for fabrication. In some cases, the name Saran is retained for the finished filaments, whereas in others, a different name is adopted. One of the best known names is Velon, which applies to the vinylidene chloride plastics and filaments manufactured by The Firestone Tire & Rubber Company.

Vinylidene chloride filaments are characterized by unusual toughness, and excellent resistance to water and chemicals. They are fire-resistant and can be given a range of beautiful colors. Thus far, the principal applications of the monofilament have been in screening and upholstery, but the development of multifilaments may open up a wide field of new uses.

HISTORY AND DEVELOPMENT

The chemical, unsymmetrical dichloroethylene or vinylidene chloride was known as early as 1840. From that time until recently, little was reported in the literature concerning it beyond the fact that it undergoes polymerization like the well-known vinyl chloride and that the polymers are unusual because they exhibit crystallinity.

The development of vinylidene chloride was actively begun over a decade ago by The Dow Chemical Company, as a result

of investigations on chlorinated aliphatic compounds. A thorough program of research was instituted, which led to the commercial introduction of vinylidene chloride polymers early in 1940.

MANUFACTURE OF SARAN

Saran is a vinylidene chloride-vinyl chloride copolymer containing less than 10% of plasticizer and various light stabilizers, pigments, etc.

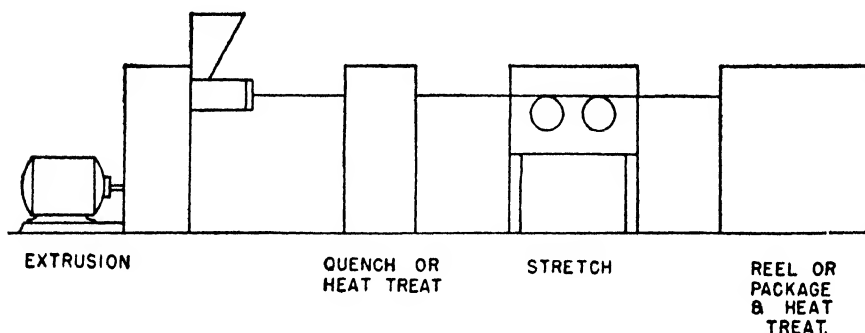
Vinylidene chloride monomer is prepared from ethylene and chlorine which combine to form trichloroethane. Ethylene is obtained from petroleum (by a cracking process) or from natural gas, and chlorine is derived from brine by electrolysis. Vinylidene chloride is a clear, colorless liquid which boils at 89° F. (31.7° C.). Its structural formula is $\text{CH}_2=\text{CCl}_2$.

Vinylidene chloride can be polymerized readily to form a long, linear chain polymer. By selection of copolymers and control of polymerization conditions, polymers may be formed having softening points ranging from 70° to 180° C. (158° to 356° F.). Soft, flexible materials, to hard, rigid materials can be obtained. Commercial polymers, with a molecular weight of approximately 20,000, have softening points between 120° and 140° C. (248° and 284° F.).

To a greater to lesser degree, Saran exhibits regions of crystal structure, which can be demonstrated readily by its x-ray diffraction pattern. Most organic thermoplastics exist in an amorphous state and do not exhibit crystallinity. Saran can be made amorphous under special conditions. When allowed to return to room temperatures, it gradually changes to its normal crystalline state showing a ring-like diffraction pattern. Amorphous Saran can be converted by mechanical working to an oriented crystalline state showing a lattice diffraction pattern.

In the production of continuous filaments, the vinylidene chloride resin must be uniformly heated to a sufficiently high temperature to insure complete melting of the resin. Thus the crystal structure of the polymer will be completely removed and totally amorphous Saran can be extruded.

After the material has left the extrusion die, it is immediately immersed in a water bath maintained at a low temperature (normally about 50° F.), so that crystallization will not take place, and a continuous filament of amorphous supercooled Saran is obtained. The material will remain in this amorphous or supercooled condition for a sufficient period of time to permit cold-working operations to be carried out. It is then ready for orientation.



Courtesy The Dow Chemical Company

FIG. 21. Orientation process for Saran.

This is effected by withdrawing the filament from the extrusion die at a uniform rate and stretching it approximately 400%. During this mechanical stretching, there is a partial recrystallization of the material and orientation of the crystallites along the major axis of the filament. The reduction in cross-sectional area is approximately proportional to the elongation which takes place. The material may be heat treated after or during stretching to affect the degree of crystallization and thus control the properties of the oriented filament. After winding and packaging, the Saran filament is ready for use.

In view of the range of material formulations and the flexibility of the foregoing process, a variety of continuous filaments with required properties can be made.

Extruded and oriented monofilaments have been produced for textile uses, ranging in size from 0.007 inch to 0.100 inch. They

have shown adaptability to standard textile operations and have been fabricated by braiding, weaving, knitting, and twisting. While many uses now exist for monofilaments in the sizes commercially available, still greater fields await single and multiple fine fibers.

PROPERTIES OF SARAN

One of the outstanding characteristics of Saran is its resistance to chemicals and solvents. At room temperature, it is extremely resistant to all acids and common alkalies, except concentrated ammonium hydroxide. When exposed to concentrated sulfuric acid or caustic over long periods, there is slight discoloration with little change in mechanical properties. It is substantially unaffected by both aliphatic and aromatic hydrocarbons, alcohols, esters, ketones, and nitroparaffins. It is swelled or softened only by oxygen-bearing organic solvents, such as cyclohexanone and dioxane. Its resistance to chemicals or solvents decreases as the temperature rises.

Another important characteristic of Saran is its extremely low water absorption and vapor transmission. Over a period of 24 hours, it shows water absorption of only 0.02 to 0.05%. This accounts for its dimensional stability and freedom from warpage under a wide range of moisture-exposure conditions.

Saran is thermoplastic and has a definite softening point, which limits the temperature at which it can be used. Since softening points vary with composition, the upper limit of operating temperature can be varied from 150° to 250° F. (65° to 120° C.). Exposures to much higher temperatures involve no fire hazard, since Saran is not inflammable.

The basic vinylidene chloride polymers are odorless, tasteless, and non-toxic. Their high refractive index enhances their many color possibilities. Their toughness and abrasion resistance are very high. Retention of these properties upon aging insures excellent wearing qualities.

TABLE 5.1. PROPERTIES OF SARAN*

Oriented Forms

Extrusion temperature	Up to 375° F.
Specific gravity	1.68-1.75
Refractive index, nD	1.60-1.63
Tensile strength, ultimate ^a	15,000-40,000 lbs./sq. in.
Elongation at yield point ^b	20-30%
Modulus of elasticity, tension ^c	0.7-2.0 x 10 ⁵ lbs./sq. in.
Flexural strength	Flexible
Thermal conductivity	2.2 x 10 ⁻⁴ cal./sec./cm. ² /°C./cm.
Specific heat	0.32 cal./°C./gm.
Resistance to heat (continuous) ...	170° F. (approx.)
Resistance to heat (intermittent) ^d ..	Shrinks above 170° F.
Softening point	240°-280° F.
Water absorption, ASTM, D570—	
40T	Less than 0.1%
Burning rate	Self-extinguishing
Effect of age	None
Effect of sunlight	Darkens slightly
Effect of acids, alkalies, solvents	None, slight
Clarity	Translucent to opaque
Color possibilities	Extensive

* Source: "Vinylidene Chloride Polymers," W. C. Goggin and R. D. Lowry, Am. Chemical Society, Atlantic City, N. J., March 18, 1942.

^a The tensile strength as shown here covers a wide range in size and degree of orientation of the stretched products.

^b Ultimate elongation is greater than that shown here, but is generally less significant.

^c The modulus of elasticity figures listed here were computed from the stress-strain curve below the yield point.

^d Oriented monofilaments retain more than 50% of their room temperature strength at 212° F., but unless restrained, they tend to shrink at temperatures of 170° F. or more.

Coloring of Saran. Vinylidene chloride filaments can be given a wide range of attractive colors by incorporating pigments in the spinning mass. Because of the impervious nature of the material, it does not take dyes by the conventional dyeing methods. However, the use of certain acetate rayon dyes has shown good results experimentally. Research efforts are being continued to find better methods of coloring.

APPLICATIONS OF SARAN MONOFILAMENTS

During the war, Saran monofilaments were used to take the place of a number of imported natural products, such as hemp, long fiber paper, reed, rattan, horschair, Spanish silkworm gut,



Courtesy The Dow Chemical Company

FIG. 22. Saran rope is strong, chemically resistant, and will not rot or corrode.

and linen. Some of these wartime substitutions may well prove to be permanent.

The following are typical applications of the monofilament:

1. Filter fabrics. The extremely high resistance of Saran to chemicals adapts it to this use. Although a thermoplastic, Saran

still retains half its original tensile strength at a temperature above that of boiling water. Normal strength is regained on cooling to room temperature.

2. Special ropes. Its high wet strength, as well as its chemical and fungus resistance, make Saran suitable for use in special ropes and cores for wire ropes.

3. Articles of apparel. Its general attractiveness and range of color possibilities fit Saran for such apparel accessories as belts, suspenders, handbags, and shoes.

4. Upholstery fabrics. The important properties for use in upholstery fabrics are long life, ease of cleaning, abrasion resistance, flexibility, and range of color. Saran in subway transportation seating showed no material wear after a year's service. It is also used in upholstery fabrics for train and bus seats, as well as for household furniture and automobile seat covers.

VELON

Following the development of vinylidene chloride as a plastic by The Dow Chemical Company, it was utilized by The Firestone Tire & Rubber Company for the production of Velon monofilaments. The following information on Velon has been specially prepared by The Firestone Tire & Rubber Company.

Before vinylidene chloride resins can be fabricated into useful products, they must be compounded with plasticizers, lubricants, and stabilizers in order to develop special properties. Plasticizers are capable of modifying the flexibility, stiffness, strength, and elasticity of the resins. Lubricants are used to facilitate fabrication and stabilizers to improve the heat resistance during fabrication, as well as aging properties of the resins. In the compounding stage of plastics preparation, colors are introduced. A broad range of colors in translucent and opaque types are available.

Velon was designed for use in the manufacture of box woven fabric and insect screening. It was found possible to weave the material on metal wire looms. Through minor loom modification, a durable insect screen was made.

Shortly after the feasibility of weaving Velon on wire looms was established, it was found possible, by applying suitable techniques, to weave a fabric on slightly modified standard textile looms. This led to further research and development work in the compounding of the resin and the design of improved extruders. Investigations involving the design of more efficient looms and a study of the technique of weaving followed.

MANUFACTURE OF VELON

Vinylidene chloride copolymer is a thermoplastic resin, which upon the application of heat softens and ultimately melts to a viscous mass that is readily extruded through dies to form continuous lengths of monofilaments. The extrusion temperature is approximately 350° F. (177° C.). The filaments, which are in a molten state upon leaving the die, are quenched in a cold bath and assume an amorphous or non-crystalline, supercooled condition. In this state, they have rather unusual properties, being quite malleable or ductile and resembling a soft metal more than a plastic. They are ductile enough to be stretched mechanically to about four times their original length to produce crystalline monofilaments. This stretching results in orientation and gives a hard, flexible filament possessing satisfactory tensile strength. As a result of the regular longitudinal alignment of the molecules in the filament, crystallization of the resin occurs and imparts stability to this form of the plastic.

Subsequent conditioning operations or treatments may be performed to bring about improvement in certain properties of the filament. Depending upon the shape of the die, different cross-sectionally shaped filaments may be extruded.

Among the earlier extruded cordages of Velon was a rattan of relatively large cross-sectional area having a width of about one-eighth inch and a thickness of 0.02 to 0.03 inch. Another early product was fishing leaders.

Most of the Velon monofilament, which was used in screening for the armed forces, was of 0.012 inch diameter. Development work has been carried to the point where 0.005 inch monofilament is commercially feasible. Since the fabrics woven from the larger diameter Velon filaments do not have the desired "hand" for certain applications, considerable effort has been made to extrude finer filaments and thus broaden the range of applications.

Weaving of Velon. Much development work has been done on improving the techniques for handling Velon in various weaving operations. The weaving of Velon commenced during the early part of 1941. Although experimental work had progressed to the point of placing the monofilament yarns on a commercial weaving basis, the war brought about the allocation of all the yarn to the armed forces.

The government needs were so urgent that there was no time to build new equipment, and it was necessary to use the equipment on hand, making certain modifications. The Hafner Associates, Inc., mills had been set up for the weaving of fine upholstery, drapery and dress goods fabrics, and their equipment was used in the weaving of 0.012 inch diameter Velon into military screening.

The yarn was received on large, wooden-barreled spools, each holding from 1 to 1½ lbs. of yarn. Larger and reinforced pins on the creel were made to hold these packages. The warping mills or frames had to be reinforced to withstand the tension and pressure which the monofilament yarn exerted. In the beginning, wooden beams were used until the more practical all-steel beams became available.

The quilling of the yarn is performed by taking the yarn overend from the spool and passing it through a set of disc tensions with spring attachment, using the regular quilling machines for this purpose.

In order to weave the heavier monofilament Velon yarns on the looms available, it was necessary to reinforce the whole train of gears on the take-up motion. Special care had to be taken so that the heavy rope let-off motion functioned smoothly and that the temples were set properly; larger heddles, heavier drop wires, and reinforced reeds were also necessary.

Since Velon becomes more flexible when heated, the application of higher temperatures is essential to render the monofilament yarn more pliable for weaving, especially in the interlacing of the ends and picks. The fabric is then subjected to a finishing operation under controlled heat and pressure.

The building of warping equipment suitable for this type of yarn, together with new and improved methods of quilling, should help to establish Velon in commercial markets.

PROPERTIES OF VELON

The outstanding properties of Velon fabrics are resistance to abrasion, resistance to soiling, and a slight degree of elasticity with full recovery which contributes to its dimensional stability in applications where unusual strains may cause distortion or bagging.

Velon monofilaments have been made having tensile strengths in excess of 40,000 lbs. per sq. in. The material is non-absorptive, does not stain, and can be cleaned easily. It also has excellent chemical resistance. Acids, most alkalies, water, alcohols, and oils have little or no effect on it at ordinary temperatures.

The material has outstanding resistance to abrasion and good low-temperature flexibility. At elevated temperatures, above 170° F. (77° C.), it is susceptible to loss of strength as a result of disorientation, which is evident from the shrinkage that occurs. By maintaining the filaments under tension at such temperatures, thus preventing shrinkage, disorientation and weakening may be prevented.

Velon is self-extinguishing and therefore presents no fire hazard. It has good aging qualities and is reasonably sunfast in

a broad range of translucent and opaque colors. The monofilaments are round, having a uniform cross section and a smooth outer surface which gives them a lustrous appearance.

TABLE 5.2. PROPERTIES OF VELON MONOFILAMENTS*

Tensile strength	40,000 lbs./sq. in.
Tenacity	1.8 gms./denier
Elongation, at break	20 to 30%
Flexural strength	Flexible at temp. as low as -40° F.
Specific gravity	1.68 to 1.75
Refractive index, nD	1.60 to 1.63
Resistance to heat	Shrinks above 170° F.
Softening point	240° to 280° F.
Thermal conductivity	2.2×10^{-4} cal./sec./cm. ² / $^{\circ}$ C./cm.
Water absorption, immersion	
24 hours	Less than 0.1%
Burning rate	Self-extinguishing
Effect of age	None
Effect of sunlight	Darkens slightly
Effect of chemicals	Generally resistant
Effect of fungus, mildew, etc.	Not attacked
Clarity	Translucent to opaque
Color range	Extensive

* Source: The Firestone Tire & Rubber Co.

Finer Filaments. The finer a filament is, the softer the "hand" of the fabric made from it. Therefore, an objective in the further development of Velon fabric is to extrude finer filaments.

A typical fabric made of 0.008-inch diameter monofilaments has the following properties:

	<i>Warp</i>	<i>Filling</i>
Tensile strength, lbs/sq. in.	160	70
Tear strength, lbs. pull	35	10
Flexural strength (No. of flexes)	75,000	40,000

VELON MULTIFILAMENTS

A relatively new development is the extrusion of Velon multifilaments. Single filaments finer than 0.001 inch in diameter have been extruded and plied into multifilament yarns which can be knitted into stockings and woven into tapestries and other fabrics.

TABLE 5.3. PROPERTIES OF 0.001" VELON FILAMENTS*

Tensile strength	55,000 lbs./sq. in.
Tenacity	2.58 gms./denier
Elongation	22%
Loop test tensile	22,000 lbs./sq. in.
Loop test tenacity	1.5 gms./denier
Loop test elongation	10%

* Source: The Firestone Tire & Rubber Co.

APPLICATIONS OF VELON

The military uses for this material included insect screens, tents, mesh inner-soles for military boots, battery separator mesh, target cloth, and collapsible stretchers.

Before the war, Velon was showing great promise for use in upholstery and drapery fabrics. It has been utilized by nine railroads, 25 buslines, 8 taxicabs, as well as by steamship lines and airlines.

The established applications include insect screens, upholstery for automobiles, railroad cars, and airplanes, furniture upholstery, decorative fabrics, filter cloths, narrow webbing, and drapery material.

The filaments may be woven into many different types of weaves, or may be braided or knitted for novelty uses. They may be used in combination with other yarns, both natural and manufactured, to give improved qualities for utilitarian or decorative purposes.

TABLE 5.4. SUGGESTED APPLICATIONS FOR VELON *

1. Fabrics: Strands and monofilaments

A. Upholstery:

Box woven construction

Fine woven

Uses:

Automotive

Airplanes

Trolley cars

Subway cars

Railroad cars

Boats

Theater and auditorium seating

Furniture

B. Other Uses:

Awnings

Beach bags and accessories

Belts

Golf bags

Gun cases

Insect screens

Hand bags

Luggage

Radio grilles

Shoes (upper materials)

Bristle for brushes

Cable, rope and twine

Fishing leaders

Fishing nets

2. Fabrics: Multifilaments

Wearing apparel

Millinery

Shoes (upper materials)

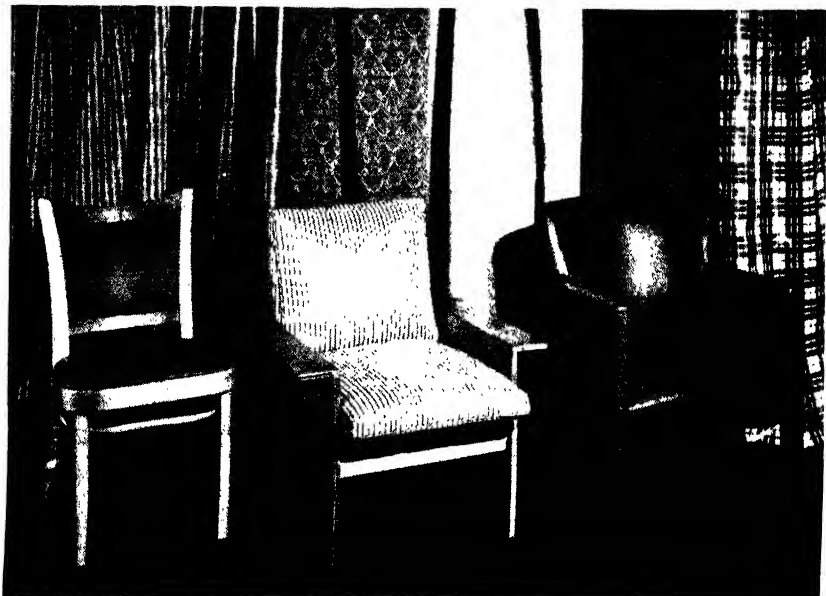
Curtains

Hand bags

* Source: The Firestone Tire & Rubber Co.

OTHER VINYLIDENE CHLORIDE FILAMENTS

The activity of Chicopee Manufacturing Corporation is limited to the development of fabrics from vinylidene chloride filament which is purchased from National Plastic Products Company in Odenton, Md. The basic vinylidene chloride powder



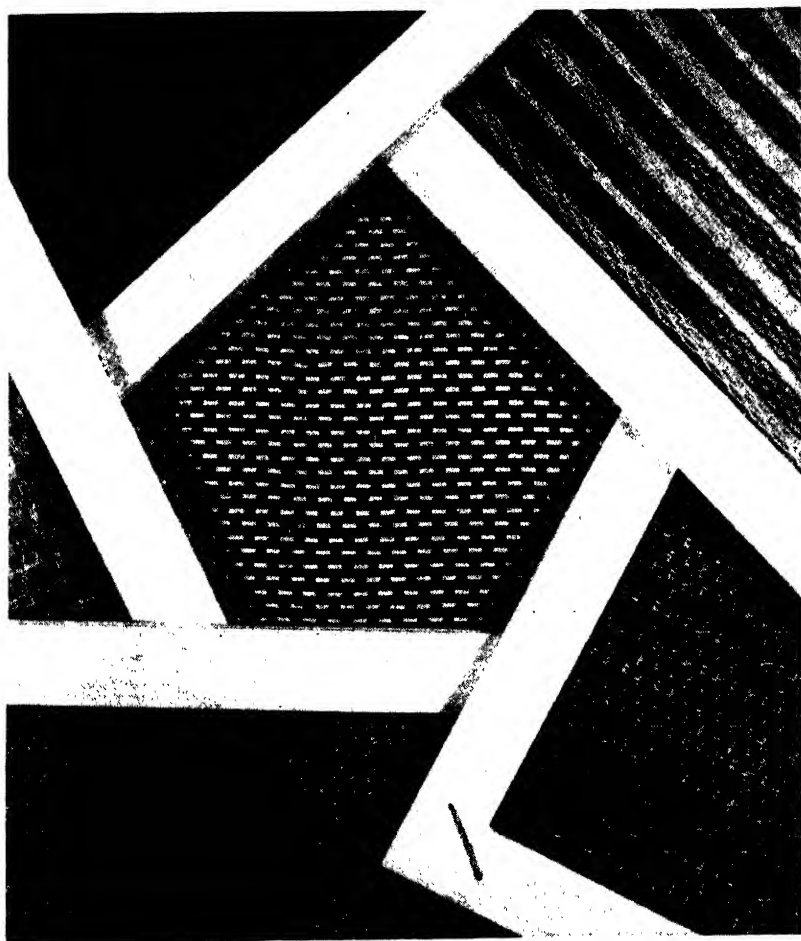
Courtesy The Firestone Tire & Rubber Co.

FIG. 23. Velon makes colorful drapery and upholstery fabrics. The material is durable and easily cleaned.

is manufactured by The Dow Chemical Company and sold to several extruders including National Plastic Products Company.

During the war, the output of Chicopee Manufacturing Corporation was used for insect screening by the armed forces in the far Pacific area. The company has been doing some development work on fabrics for use in upholstery for porch and transportation seating, as well as in shoes, handbags, and luggage.

The Visking Corporation is also a producer of Saran monofilaments.



Courtesy The Dow Chemical Company

FIG. 24. Fabrics made from Saran monofilaments by the Chicopee Manufacturing Corp.

PRODUCTION AND PRICE DATA

Output of vinylidene chloride fibers during the war period was approximately 1 million pounds annually. It was allocated mainly for screening, used principally in the South Pacific.

The prewar price of the filament ranged from \$1.00 to \$3.00 a pound. Detailed prices as of 1945 are shown in the accompanying table.

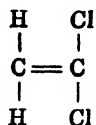
TABLE 5.5. PRICES OF VELON MONOFILAMENTS*

<i>Diameter (In.)</i>	<i>Price per Pound</i>
0.030	\$0.75
0.020	0.75
0.012	0.95
0.008	1.20
0.006	1.20

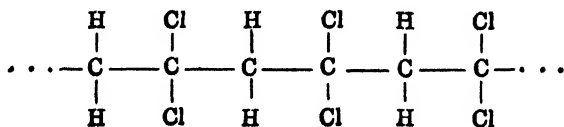
* Source: The Firestone Tire & Rubber Co.

CHEMISTRY

Vinylidene chloride, a di-substituted ethylene compound, has the structural formula—

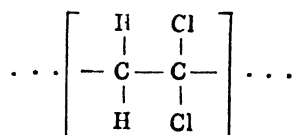


Vinylidene chloride readily polymerizes to form a straight-chain polymer which is completely saturated. Its structure is represented by the long chain—

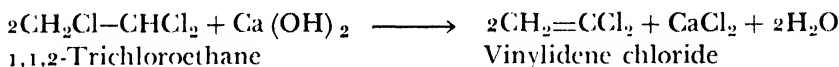


Polyvinylidene chloride

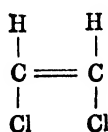
The structural unit of polyvinylidene chloride is—



Monomeric vinylidene chloride, 1,1-dichloroethylene, can be prepared from—

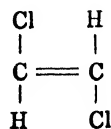


The isomers of vinylidene chloride, *cis*- and *trans*- 1,2-dichloroethylene, polymerize only with great difficulty. The structural formulas of these isomers are—



cis-

and



trans-

1,2-Dichloroethylene

The basic structure, $\text{CH}_2 = \text{C}$, of vinylidene chloride is similar to that of the vinyl compounds which have the characteristic grouping, $\text{CH}_2 = \text{CH}-$. In general, the technique of vinyl chloride polymerization is applicable to vinylidene chloride.

An important and fundamental property of polyvinylidene chloride is its crystallinity. Copolymerization with other

monomers introduces units in the chain which tend to destroy its regularity and consequently its ability to crystallize. The upper limit of the amount of copolymerizable material which may be included without destroying the crystallinity of the copolymer varies somewhat with the structure of the copolymerizing molecule. Some typical compounds which are copolymerizable with vinylidene chloride are the following:

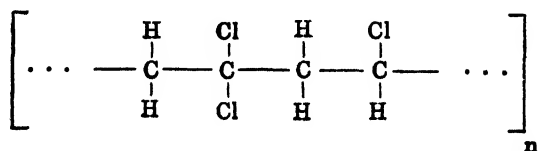
Maximum Proportions of Monomers in Vinylidene Chloride Copolymers Which Exhibit Crystallinity

Per Cent by Weight

Vinyl chloride	15
Vinyl acetate	15-20
Vinyl cyanide (acrylonitrile)	20 or more
Styrene	12-15
Methyl acrylate	15
Ethyl acrylate	15
Methyl methacrylate	15
2-Chloroallyl chloroacetate	15
Ethyl 2-methallyl ether	15

In general, copolymers which contain more than 80% and preferably more than 85% by weight vinylidene chloride exhibit crystallinity and under suitable conditions can be cold drawn into molecularly oriented fibers.

Vinyl chloride, $\text{CH}_2=\text{CHCl}$, is present in the vinylidene chloride copolymer sold by The Dow Chemical Company under the trade name *Saran*. The structural formula of the copolymer may be represented as follows:



REFERENCES

1. "Vinylidene Chloride Polymers," W. C. Goggin and R. D. Lowry, The Dow Chemical Co., Midland, Mich., March 18, 1942.
2. "Vinylidene Chloride Polymers," R. C. Reinhardt, *Industrial and Engineering Chemistry*, Vol. 35, April 1943, p. 422.
3. "Vinylidene Chloride Yarns Now Woven into Goods," H. R. Mauersberger, *Rayon Textile Monthly*, October 1942, p. 69.
4. "Dow Reports on New Developments with Saran," *Rayon Textile Monthly*, February 1944, p. 58.
5. "New Textile Applications for Saran," *Rayon Textile Monthly*, September 1943, p. 91.
6. "Velon Fabric," The Firestone Tire & Rubber Co., Akron, Ohio.



Courtesy Owens-Corning Fiberglas Corporation

FIG. 25. Fiberglas staple fiber can be twisted and plied into yarns.

CHAPTER VI

Glass Fibers

SUMMARY

Glass fibers are outstanding among textile fibers in four important respects: (1) high tensile strength, (2) complete fire-proofness, (3) immunity to microorganisms causing mildew and other forms of deterioration, and (4) excellent resistance to most chemicals.

On the other hand, glass textiles in their present state of development have certain undesirable properties which limit their field of potential use. Although they possess unusually high tensile strength, they lack resiliency and ability to stretch. Glass-fiber yarns have an extensibility of only from 1 to 3%, considerably below that of common textile yarns, and the fabrics made from the former are correspondingly deficient in this property. Also, in spite of their extreme fineness, glass-fiber yarns are more brittle and less flexible than those made from ordinary textile fibers. Moreover, glass-fiber fabrics are not soft to the touch, and they lack durability when subjected to a great deal of bending. For these reasons, they are not generally suitable for wearing apparel.

Glass-fiber textiles have proved to be suitable only for a limited field of uses. Nevertheless, they possess decided advantages in the uses for which they are adaptable. For instance, glass-fiber filter cloths and anode bags for electroplating are valuable in certain chemical industries. Tapes and yarns of glass fiber are used to a limited extent to insulate motors, transformers, and other types of electrical apparatus. A novel wartime use was in parachute flare shades.

Potential expansion in the use of glass fibers would seem to be greatest in fields where a fireproof fabric is desirable; for instance, in awnings, screens, lampshades, and curtains. Glass-



Courtesy Owens-Corning Fiberglas Corporation

FIG. 26. Fibreglas continuous filaments. These are twisted together to form yarns and threads for the manufacture of textiles.

fiber textiles, however, are still in such an early stage of development that it is unsafe to hazard a guess as to the uses for which they may eventually be found suitable.

HISTORY AND DEVELOPMENT

The quest for a pliable glass can be traced back many centuries. The Venetians learned how to draw glass into hair-like strands possessing some degree of flexibility. They used these strands to decorate their glassware and were the first to realize the physical principle that the flexibility of glass varies with its diameter. Venetian glass became famous throughout Europe and the secrets of its manufacture were jealously guarded by its craftsmen.

In 1893, Edward D. Libbey, of the Libbey Glass Company, succeeded in drawing, from the heated ends of glass rods, coarse fibers which were wound on large revolving drums. The fibers were worked together with silk threads into a fabric that was made into lampshades, which were shown at the Columbian Exposition in Chicago. There, a famous actress saw them and arranged to have a dress made of the same fabric. The idea of a glass dress fascinated Princess Eulalie of Spain who determined to have one, which is said to have cost \$30,000. However, these glass fibers were not sufficiently flexible, nor was the fabric entirely of glass. Glass was the warp, silk the fill. The fabric was of no practical value, since it could not be folded without splitting.

In the early 1900's a number of patents were issued in Germany and in England on various processes for drawing finer fibers from glass. The fibers produced were still too coarse for use in weaving practical fabrics, but they were used to some extent in thermal insulation, particularly in Germany during World War I.

The first important step in the development of a successful glass fiber was made in 1931, when a program of research was initiated in the United States by Owens-Illinois Glass Company, the leading glass container manufacturer, and by Corning Glass Works, well-known producer of glass specialties. Considerable experimental and development work was carried out with a view to the production of glass in a commercially usable fiber form.

Gradual progress was made, both in improving manufacturing processes and in developing new markets.

Relatively coarse glass fibers, coated with adhesive, proved their value in air filtration. Finer glass fibers, in wool-like form, made steady gains in the field of thermal insulation. Still finer and stronger fibers were produced, and by 1936 it was possible to make fibers pliable enough to be woven into all-glass fabrics that could be creased and folded. New uses in the fields of electrical insulation and decorative fabrics were developed in quick succession.

Late in 1938, Owens-Corning Fiberglas Corporation was formed to continue the manufacture of glass fiber materials, to carry on further research, to explore additional new uses, and to adapt the materials to still other uses based on their inherent properties. The new company acquired all the assets that Owens-Illinois Glass Company and Corning Glass Works had devoted to the development and manufacture of Fiberglas, and, in exchange, the two latter companies each accepted 50% of the stock of the new company.

COMMERCIAL MANUFACTURE

The first step in the manufacture of Fiberglas is the selection, mixing, and melting of the raw materials. By varying the ingredients and their proportions, by regulating the temperature, and by controlling the fiber diameter, the fibers are given the special properties required.

Five different types of glass are used in the production of standard Fiberglas products. Each is formulated to produce a glass having desired characteristics for particular uses.

Type E glass is designed for electrical applications, although it also possesses good chemical resistance and is highly durable. It is a borosilicate glass that contains no alkali-metal oxides. It is used only in continuous and staple textile fibers.

Type C glass is designed for chemical applications, such as filter cloths and anode bags. It has good resistance to mild alka-

lies and to most acids. It is produced only in staple fiber form.

Type T glass is designed for thermal insulation and acoustical uses. It has high durability and weathering resistance. It is a general purpose borosilicate glass used for all commercial wool products.

Type N glass is specially formulated to meet the requirements of Navy Department Specification 32-G-2 and is processed only in the form of insulating wool for Navy and certain aircraft uses.

Type F glass is designed for use in the form of relatively coarse filter fibers. It is a soda-lime silicate glass.

The primary ingredients for the various types of glass are silica sand and limestone. In addition, varying quantities of aplite, alumium hydrate, Rasorite, and other minerals are used. Soda ash is used in type F glass, borax or related compounds in others.

There are two basic types of glass *fibers*:

- (1) Fibers which are interlaced in a resilient wool-like mass for fabrication into bats, blankets, boards, and other forms.
- (2) Fibers which are twisted and plied into yarns which, in turn, are woven into braids, tapes, and cloths.

In the manufacture of the first type of fibers (the so-called "wool" process), the raw materials are melted and refined in large furnaces holding 40 tons or more. The molten glass flows from the furnaces in thin streams. Jets of high-pressure steam hit the streams of glass with terrific force and yank them into thread-like fibers. The fibers fall upon a conveyor belt, in a fleecy, resilient mass. For some thermal insulation applications, the glass wool is used in this form. For other thermal applications it may be treated with a binder, compressed, and shaped into rigid or semi-rigid boards.

Another adaptation of the same process makes coarser fibers for use in air filters and eliminator mats.

In the manufacture of the textile fibers two processes are employed—the continuous filament process and the staple fiber process. These processes begin with accurate batch formulation, glass melting, and refining, the last operation taking place in

small furnaces. From these, the molten glass is transferred to a marble-forming machine, which makes small glass marbles about five eighths of an inch in diameter. The purpose of marble formation is to permit visual inspection of the glass to eliminate impurities, such as stones or bits of refractory material that would in-



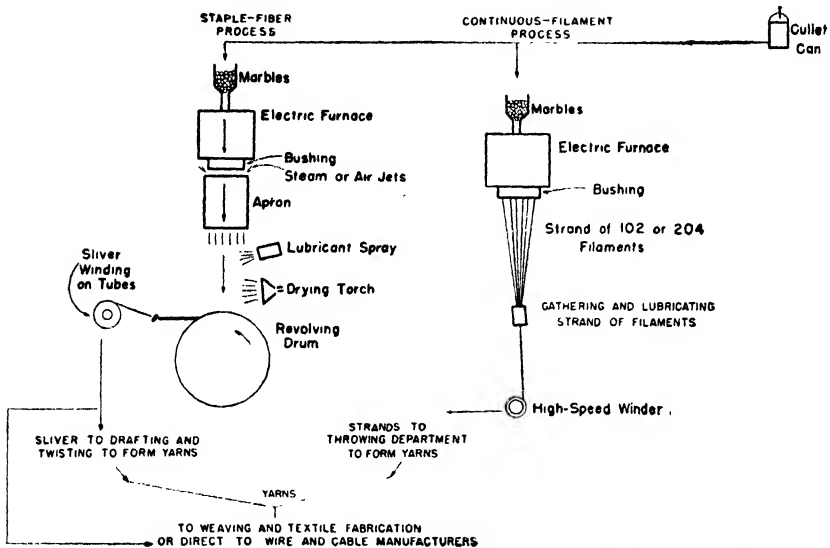
Courtesy Owens-Corning Fiberglas Corporation

FIG. 27. The semi-rigid form of Fiberglas insulation comes off the conveyor at any desired thickness and density. Sharp circular knives trim the edges and a center blade separates the stream of wool.

terfere with subsequent operations or impair the fibers. The marbles are then remelted in electric furnaces. After this, the two textile processes differ.

In the continuous filament process, more than 100 filaments are drawn simultaneously and gathered into a strand. The strand is attached to a high-speed winder that, as it draws the strand,

attenuates each stream of glass where it emerges from the furnace, reducing its diameter to a fraction of the diameter of the hole through which it emerges. From a single marble, 97 miles of a single filament can be drawn. The length of the continuous filament strands is limited only by packaging requirements. The strands could be drawn to indefinite lengths, running to thousands of miles.



Courtesy Mining Technology

FIG. 28. Flowsheet of the Fiberglass-textile processes.

In the staple fiber process, the molten glass also flows in thin streams through small holes in the base of the furnace and is struck by jets of high-pressure air or steam which yank the glass into fibers varying in length from 8 to 15 inches, which is longer than the best long-staple cotton. The fibers are driven down on to a revolving drum on which they form a veil resembling a cobweb. In their almost instantaneous passage to the drum, they go through a spray of fiber lubricant and a drying flame. The gossamer web of fibers is gathered from the drum into a sliver that is lightly drafted in the succeeding winding operation, so

that the majority of the fibers lie parallel with the length of the strand. The staple-fiber sliver can be further drafted, if desired.

Strands of either continuous filament or staple fiber are twisted and plied into yarns on textile machinery similar to that used for making cotton and worsted yarns. Fabrics woven of continuous filament yarns are thin, smooth and lustrous. Fabrics woven of staple yarns have a slightly fuzzy appearance and are less lustrous.

PROPERTIES OF GLASS FIBERS

The various fabricated forms of Fiberglas have different properties, but the fibers themselves possess certain properties that are basically responsible for the wide range of uses of this material.

Flexibility is the property of glass fibers which distinguishes them from all other forms of glass. However, they are less flexible than other fibers. Glass fibers are flexible because they are extremely thin in relation to their length. A somewhat comparable material is steel which is rigid in a thick, short piece, but very flexible when drawn out into a fine wire. The same is true of glass, but to be really flexible the diameter of the glass must be much smaller, relative to its length, than is required in the case of steel.

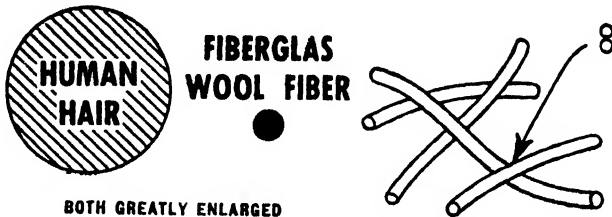
From a hundred to several hundred fibers or filaments are gathered together to form a fine strand. When such a strand is folded or knotted, it is unlikely that any single fiber will be bent more sharply than it can tolerate without breaking. Hence, its flexibility.

Another important property of Fiberglas—one which distinguishes it from other fibers—is incombustibility. The finished yarns are incombustible except for the fiber lubricant. The lubricant can be burned off the yarns under certain conditions, but the glass yarn itself cannot burn. Fiberglas will sinter or melt, and a flame will leave a black deposit of carbon, but the material will not give off smoke or any noxious gas. This prop-

erty is highly important in textile applications, particularly in draperies for use in places of public assembly.

Glass fibers have a higher tensile strength-weight ratio than any other commercial material. Fibers averaging $23/100,000$ of an inch in diameter have a tensile strength of about 250,000 lbs. per sq. in.

Tensile strength of standard Fiberglas textile fibers is of the order of 200,000 lbs. per sq. in. The tensile strength increases as the fiber diameter decreases. Average fiber diameters range from 23 to 28 one-hundred-thousands of an inch. Experimental



The high insulating value of Fiberglas comes from two sources: the millions of entrapped air particles—the wool is 92 to 99 per cent air by volume—and from the difficulty with which heat moves from one fiber to another.

The glass fibers are smooth, cylindrical, hard and resilient—and only about one sixth the diameter of a human hair. Where they cross and touch each other they have exceedingly small contact points; hence, heat cannot easily pass from one fiber to the next. These two factors assure low thermal conductivity in all the forms in which Fiberglas wool is fabricated for industrial insulation uses.

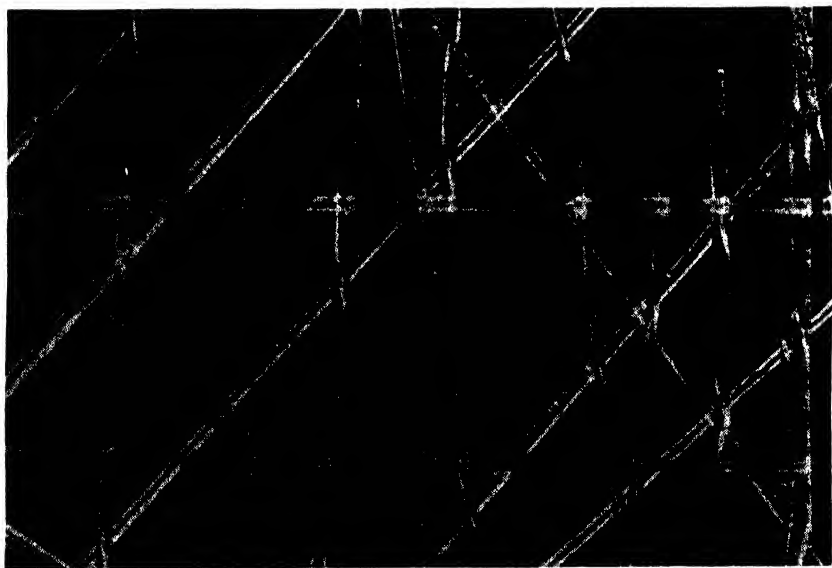
fibers have been produced with diameters as low as $2/100,000$ of an inch and with tensile strengths as high as 3,500,000 lbs. per sq. in.

An unusual feature of glass fibers is that they have tensile strengths in excess of those of the high-strength metals, and yet they have many times the elongation of such metals before the elastic limit is reached. In glass fibers, the elastic limit and the ultimate strength are one and the same. They are quite different for metals.

Although glass yarns have great tensile strength, they have little or no stretch. However, the individual fibers are perfectly elastic and at maximum stress show an elongation up to 3%.

This property contributes dimensional stability combined with ability to absorb unusual stresses.

However, the tensile strength of glass fiber is reduced greatly by adsorption of atmospheric moisture on the surface. This condensation or adsorption takes place upon any glass, and apparently cuts the strength from a few million pounds per square



Courtesy Owens-Corning Fiberglas Corporation

FIG. 29. Glass fibers resemble smooth glass rods of very small diameter as shown by this photomicrograph.

inch down to a few hundred thousand pounds. Further, the strength of fibers is greatly reduced by abrasion.

The modulus of elasticity remains fairly constant at 8 to 9 million lbs. per sq. in. for glass fibers between 70/100,000 to 20/100,000 of an inch in diameter—a range which includes the standard textile fibers. An upward trend is shown for fibers of smaller diameter.

Glass fibers have high dimensional stability, since they do not swell under the influence of moisture and elongate only under

great tension. They are essentially tiny glass rods, and because they have no cellular interstructure, they cannot absorb moisture. Their surfaces can be wet, but moisture cannot enter the individual fibers. Moisture adsorption (gain in weight due to water vapor from humid air) is less than one tenth of 1% by weight. The fibers do not swell, stretch, or shrink under the influence of moisture changes.

Glass fibers will not rust, rot, or mildew. They are the result of oxidation and, unlike metallic and organic fibers, can exist indefinitely in an atmosphere of oxygen. The fibers are unaffected by weak alkalis and by acids in their most concentrated forms, except hydrofluoric and phosphoric acids.

Glass in both the bulk and fibrous forms has about the same specific gravity as cast aluminum. The figures are 2.5 for glass and 2.6 for aluminum. However, a cubic foot of uncompressed glass fibers of the wool-like type used for thermal and sound insulation weighs only 1.5 lbs., approximately one hundredth as much as a cubic foot of bulk glass.

As regards weathering characteristics, Fiberglas materials have undergone accelerated weathering tests for several years without apparent change. This would seem to indicate comparatively unlimited stability under repeated cycles of heat, cold, condensation and drying.

PROPERTIES OF GLASS FABRICS

It may be interesting at this point to compare the properties of glass fibers with the properties of yarns and fabrics made from them.

The strength of the yarn and fabrics is inevitably less than the strength of the individual fibers and is affected by the construction of the yarn and weave of the fabric. The breaking strength of glass yarns and fabrics, however, is considerably higher than that of other textile materials of comparable thickness and construction.

TABLE 6.1. FIBERGLAS BASIC FIBERS

Fiber No.	Glass Type	Fiber Diameter		Fiber length (average) (in.)	Fiber lubricant or coating	Surface area per pound of glass (sq.ft.)	Average Pack Density (lbs./cu.ft.)	Minimum Service Density as Filler	
		Average (in.)	Range from average (in.)					Max. F.P.M. or pressure drop	Density
800	F	.00800	± .00050	20	None	38.7	3.5	400 F.P.M.	4.00
600	F	.00600	± .00050	20	None	47.5	3.5	400 F.P.M.	4.12
450	F	.00450	± .00050	20	None	68.8	3.5	400 F.P.M.	4.25
85	E	.00085	± .00015	15	None	355.0	2.0	5" w.g.	3.00
55	T	.00055	± .00030	6	Min'l oil	537.0	1.5	5" w.g.	3.80
28	E (C) †	.00028	± .00005	15	None	1079.0	2.2	5" w.g.	4.00
22	E	.00022	± .00005	16	Starch	1370.0	1.5 ‡	5" w.g.	6.00

* Source: Owens-Corning Fiberglas Corp.

† No. 28 Fiber is normally made of E Glass. It can be produced from C Glass (C28) if volume and use warrants.

‡ Density after de-starching or spreading and fluffing. Density before spreading bundles of fibers may range up to 70 lbs. per cu. ft. or more.

TABLE 6.2. PROPERTIES OF "E" GLASS

Specific gravity	2.54
Thermal expansion	$27 \times 10^{-7}/^{\circ}\text{F.}$
Index of refraction for sodium light	1.55 ± 0.01
Power factor at 10 megacycles	0.0015
Dielectric constant at 10 megacycles	5.8
Annealing point	1200° F.
Softening point	Approx. 1540° F.
Strain point	1140° F.

TABLE 6.3. PROPERTIES OF YARN MADE OF "E" GLASS * †

Fiber diameter	0.00023 to 0.00028 in.
Fiber length	Continuous
Fiber cross-section	Approximately circular
Yarn diameter	0.00028 to 0.040 in.
Tenacity	6.5 gms./denier, dry 6.0 gms./denier, wet
Tensile strength	Average 213,000 lbs./sq. in.
Elongation at break	2% to 3% dry
Elastic recovery	100% at 3% elongation
Temperature resistance	Strength increases up to 400° F. and decreases to a practical working limit for most textile products at 1000° F.
Acid resistance	Attacked by hydrofluoric and hot phosphoric acids
Alkali resistance	Attacked by hot solutions of strong alkalies
Solvent resistance	Insoluble in organic solvents

* Source: Owens-Corning Fiberglas Corp.

† The "E" glass referred to in the table is designed for electrical and general purpose applications. A "C" glass is occasionally used for the manufacture of yarns to be employed in such specialized applications as chemical filtration cloths. Except for the fact that it has superior chemical resistance, the fiber characteristics are substantially the same as those given for "E" glass.

The dimensional stability of the glass fiber is retained in the yarns and fabrics. Like the fibers, the yarns show an elongation up to 3% at maximum tension. Fabrics have little or no stretch, except that due to the weave. Moisture changes do not cause stretch or shrinkage.

The lower limit of the plastic flow of glass textile fibers is about 200° C. (392° F.). The thermal coefficient of linear expansion is 49×10^{-7} per ° C. for temperatures up to 300° C. (572° F.). An increase in the tensile strength of glass cloth is obtained by subjecting it to temperatures as high as 200° C. (392° F.). The cloth can be subjected to higher temperatures for short periods without serious loss of strength.

Virtually no shrinkage of the cloth occurs at temperatures below 100° C. (212° F.). At 400° C. (752° F.) shrinkage is only 0.30 to 0.35%. Between 375° and 425° C. (707° and 797° F.), the rate of shrinkage increases sharply. It continues to rise beyond this range, although at 600° C. (1112° F.) the shrinkage is only 0.90%.

Abrasion Resistance. Glass textiles, when properly impregnated, have adequate resistance to abrasion under actual service conditions. Glass is notably resistant to abrasion by other materials, but *glass will cut glass*. For this reason, flexing and abrasive rubbing of unimpregnated glass textiles should be avoided. When impregnated, the very fine glass fibers are covered with a protective film which keeps them from abrading themselves.

The flexing strength and abrasion resistance of glass fabrics when wet is considerably lower than when dry. This is particularly true in the case of wetting by acid solutions. Alkaline solutions have less effect than acid solutions.

Impact Strength. The high tensile strength of glass fibers, when impregnation has given them fixed lubrication, serves to distribute stresses caused by impact to such an extent that their impact strength in impregnated fabric form is high.

COLORING OF GLASS FIBERS AND FABRICS

The future of glass fabrics as a decorative material depends to a large extent upon the development of satisfactory coloring and printing processes.

The principal limiting factor has been the complete imperviousness of the glass fibers, and their consequent lack of affinity for conventional dyes. Attempts to solve the problem were made by introducing color into the molten glass, before the fibers were formed. However, it was found that when the glass was drawn into very fine filaments the colors became so attenuated that only a few pastel shades could thus be obtained. Also, because of the high temperatures involved, only ceramic colors could be used.

Recently, research has been conducted in the dyeing and printing of Fiberglas with resin-bonded pigment dyes. Dyes are being developed by a number of companies, including Aridye Corporation, Fair Lawn, N. J.; General Dyestuff Corporation; and Calco Chemical Division, American Cyanamid Company, New York. Fiberglas fabrics are being dyed with conventional dyeing equipment, and with a fairly broad range of pigment colors.

Processes employed are similar to those used for dyeing rayon fabrics, although consideration must be given to the special properties of the material. A first step is to sew the pieces end-to-end on a triple-needle machine, or on a Merrow-type butt-seam machine adjusted to give a long stitch. The fabric is then scoured on jigs or on a continuous open-width soaper, utilizing a hot solution of soap containing a small amount of mild alkali. After the fabric has been dried and batched on rolls it is ready to be dyed.

The pigment colors are applied to Fiberglas fabrics from emulsions of the water-in-oil type. The colors contain a high concentration of pigments dispersed in a resin solution and are

reduced to the proper concentration by addition of a special "clear," together with a petroleum solvent and water.

The fabrics are dyed by padding them with the pigmented emulsion on a two-roller or three-roller padder of the same type as that used for cotton fabrics. The fabrics are dried on cans, in an air dryer, or in a range consisting of a pre-dryer and dryer. The drying operation is less critical than that for rayon fabrics, and high-temperature curing is unnecessary. If desired, the fabrics can be batched on rolls after padding and before drying.

Glass fabrics are printed with pigment colors on conventional equipment, the same as for rayon fabrics. Photographic prints have been reproduced experimentally. After printing, the fabrics are dried on cans. No curing or aging is necessary. The process of printing glass fabrics is not as far developed as the dyeing process.

Glass fabrics can be dyed uniform light shades of great brilliance having excellent fastness to light, through proper selection of pigment colors. Thus far, darker shades have been less satisfactory; the darker dyes tend to stiffen the fabric, and increase the amount of crocking. The dyed fabrics can be dry cleaned, provided care is taken in handling them.

Slight crocking occurs in all glass fabrics dyed with pigment colors. In the lighter shades, the degree of crocking is not objectionable when the fabrics are used for draperies or in other applications where they are not subjected to rubbing.

It is not believed that present processes of dyeing and printing glass fabrics with pigment colors are the final answer, and research work on the problem is being continued.

APPLICATIONS

The first commercial use of glass fibers was for air filtration. Mats of relatively coarse fibers, treated with an adhesive, were employed to strain dust and pollen from the air circulated by forced-warm-air heating systems and air-conditioning systems. Retainer mats for storage batteries represent another early use of Fiberglas that has become standard.

More than 100 different Fiberglas products are made from four basic forms of this material. These are:

<i>Basic Forms</i>	<i>Primary Uses</i>
Wool	Thermal insulation Sound absorption
Filter and Aeration	Air filtration Aeration packs for industrial processes, including tower packing
Mat	Storage battery retainer mats Acoustical surfacing Filtration Reinforcement for electrical insulating plastics
Textile	Electrical insulation Industrial textiles (high temperature) Reinforcement in laminates, plastics, etc. Chemical filtration Decorative fabrics

Textile Applications. Fiberglas tapes, braids, cloths, and sleeveings impregnated with a suitable varnish are widely used as electrical insulation in motors, generators, transformers, and other electrical units. Glass tapes and cloths are employed to wrap insulated piping in ships and exhaust pipes on planes. The chemical industry uses glass fabrics to filter hot concentrated acid solutions.

Two war developments will result in new uses for glass textiles in the industrial field: (1) reinforcement of plastics, and (2) glass cloths coated with synthetic rubbers or resins.

In fabricating glass-reinforced plastics, layers of the cloth are impregnated with a low-pressure, thermosetting resin and are placed, one on top of another, until a laminate of the desired thickness is built up. The laminate is then draped over, or shaped in, a mold. The mold and the laminate formed to the desired shape are placed in an oven where the laminate is cured.

These laminates have extremely high tensile strength relative to their weights. Test specimens have shown tensile strengths

of from 50,000 to 80,000 lbs. per sq. in., compression strengths exceeding 50,000 lbs. per sq. in., and impact strengths of more than 30 foot-pounds, as compared with 2 foot-pounds for ordinary plastics.

Wartime applications of glass-plastics laminates included aircraft parts such as cabin structures of helicopters built for the armed forces. Carrying cases for the Navy's high-precision optical instruments were made of laminated vinyl- and phenolic-impregnated glass fabric. Potential peacetime applications include strong light-weight luggage, boats and canoes, furniture, kitchen and bathroom assemblies, refrigerator and radio cabinets, and other products where a combination of light weight with high strength and ease of fabrication are required.

Glass fabrics coated with synthetic rubbers and resins were used by the armed forces during the war. These coated fabrics have high tear strength and high dimensional stability. They withstand repeated flexing, and are resistant to destruction by fungi and bacterial growths. Other properties vary with the coating employed, but rubber-coated glass fabrics have been produced which are flameproof and have high resistance to moisture penetration, and to the effects of contact with gasoline, oil, chemicals and greases.

Wartime applications of coated-glass fabrics included hangar door curtains, aircraft battery covers, oil-pressure switch diaphragms, aircraft tape for expansion joints of hot-air ducts, water-storage tanks for troops in the field, and protective clothing for workers in chemical plants. Potential peacetime uses include tarpaulins, and other waterproof covers for machinery, waterproof containers for delicate instruments, wading pools for children, and carburetor diaphragms. Another possibility is an awning that will not burn if a lighted cigarette is dropped on it.

Because glass fabrics will not shrink or stretch and are proof against moths, mildew, and decay, they are suitable for drapery materials in the home. This would be particularly true of seashore homes where salt air and strong sunlight have a deleterious

effect on some of the more common drapery materials, and where high humidity often causes them to stretch and sag.

However, glass fabrics are not suitable for upholstery fabrics or for other applications where they would be subjected to re-



Courtesy Owens-Corning Fibreglas Corporation

FIG. 30. Fibreglas is particularly well adapted for use in draperies in places of public assembly, since it is entirely fireproof.

peated flexing or friction. This also excludes their use for wearing apparel.

One of the big advantages of glass fabrics over other fabrics is that they are incombustible. It is anticipated that their chief market will continue to be in places of public assembly where

there is a fire hazard. Such applications include draperies, as well as ceiling and wall coverings, for night clubs, restaurants, schools, railroads, ships and airplanes. The uses of glass fabrics will be limited to special products, such as tablecloths, overdrapes, curtains, shower curtains, bedspreads, awnings, lamp shades, and window dressing in stores.

Combinations of glass fibers with other fibers such as cotton, rayon, or silk, have interesting possibilities in decorative fabrics. The glass fibers would give unusual design effects and added dimensional stability to such fabrics. Considerable research is under way on such combinations.

Other Applications. The basis of all forms of glass thermal and sound insulation is a white, resilient blanket, of predetermined thickness, consisting of a mass of intricately interlaced glass fibers. The wool-like blanket can be fabricated into bats, rolls, bulk fibers, and shredded fibers. It can be faced with paper, fabric, or metal mesh. It can be compressed, treated with a small amount of thermosetting resin, and fabricated into preformed materials such as sheets or boards, blocks, and molded-pipe coverings.

The bat, roll, bulk and shredded forms of glass fibers are suitable for use in all temperatures from subzero to approximately 1000° F. (538° C.). Bats and rolls are used widely in stoves, roasters, water heaters, industrial ovens, and also for some applications in factories, railroad cars, ships, buses, and trucks. The bulk form is generally employed as an accessory material for stuffing and packing into odd spaces. Shredded glass fiber insulation is used wherever pneumatic application is required.

Fiberglas semi-rigid or rigid sheets or boards can be used in all types of low- and medium-temperature equipment up to about 600° F. (316° C.). In equipment operating at temperatures above 450° F. (232° C.), the resin used as a binder disappears from the hot side, leaving a layer of unbonded fibers which insulates with unimpaired efficiency up to 1000° F., as long as

enclosed by supporting surfaces. An important use of glass-fiber board is for shipboard hull and bulkhead thermal insulation.

SUPERFINE GLASS FIBERS

The production of superfine glass fibers for military purposes was undertaken by Owens-Corning Fiberglas Corporation during the war. These fibers were used for the heat and sound insulation of military aircraft where they made possible substantial savings in weight. The material is made by the extrusion of microscopically fine threads of glass under high temperatures. The fiber diameter averages 0.00008 inch. A cubic foot of the fibers weighs less than a pound.

PRODUCTION AND PRICE DATA

Output of commercial types of Fiberglas has risen rapidly since it was introduced, particularly during the war period. Sales in 1939 were about \$3,000,000, but by 1944 exceeded \$56,000,000, an increase of nearly twenty times within a 5-year period.

Continuous-filament yarns range in price from \$1.12 to \$2.15 per pound, depending on the construction of the yarn and fiber size. The staple fiber ranges from \$0.35 to \$1.00 per pound, depending on count, ply, and fiber size.

RESEARCH AND THE FUTURE OF GLASS FIBERS

Research and development work have played a vital role in the growth of the glass-fiber industry. There have been six general research objectives: (1) improved methods of production and lower costs; (2) improved binders, lubricants, and related materials; (3) new fiber forms, new products, and improvements in existing products; (4) new uses and improved methods of application in present uses; (5) the study and measurement of properties of glass fibers; (6) development and production of specialized fiber-forming and experimental equipment.

Several indications of future trends are already visible. Glass fibers having a tensile strength exceeding a million pounds per square inch have been made. Fabrics have been produced with a temperature tolerance of 2000° F. (1093° C.) instead of 1000° F. (538° C.) now common to existing glass cloth. The field of admixtures of glass fibers with other materials, such as asbestos, cotton, rayon, linen, silk, hemp, and various plastics and cements, has hardly been explored.

A new basic material has been created, and a new and promising industry has been brought into being through the development of glass fibers.

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Courtesy Bakelite Corporation

FIG. 31. Polyethylene monofilaments in a wide range of colors can be utilized in most knitting or weaving operations.

CHAPTER VII

Polyethylene Fibers

SUMMARY

Polyethylene resin went into volume production for plastics during the war, but the filaments made from it are still in the experimental stage.

Of all the fiber-forming materials, polyethylene has the simplest chemical structure and is the lightest in weight. It is the only one with a specific gravity less than that of water. It does not absorb water and has excellent chemical and electrical properties. It is highly resistant to mildews, microorganisms and insects.

Filaments made from polyethylene have good tensile strength and high elasticity. They can be given an unlimited range of colors. Disadvantages are its low softening temperature and inflammability.

Polyethylene monofilaments can be used for making marine ropes and halyards, filter cloth and insect screening. The multifilaments may have a wide range of applications pending their successful development.

DEVELOPMENT

Filaments have been produced in the United States and in Great Britain from polyethylene resins, a new group of thermoplastic materials. Production of these resins was announced in 1944 by E. I. du Pont de Nemours & Co., Inc. (using the process and generic name "polythene" introduced by Imperial Chemical

Industries, Ltd., of Great Britain) and also by Carbide and Carbon Chemicals Corporation.

Polyethylene resins are straight-chain polymers of ethylene, a petroleum derivative. They are produced by the direct polymerization of liquid ethylene at high temperatures and high pressures.

Apart from being produced at pressures higher than those used in any other industrial chemical process at the present time, polyethylene is unique in that it is the simplest synthetic thermoplastic and that its principal crystalline constituent represents the simplest type of crystalline structure in hydrocarbons. It is composed of long chains of methylene groups ($-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_2-$) of 1000 units or more.

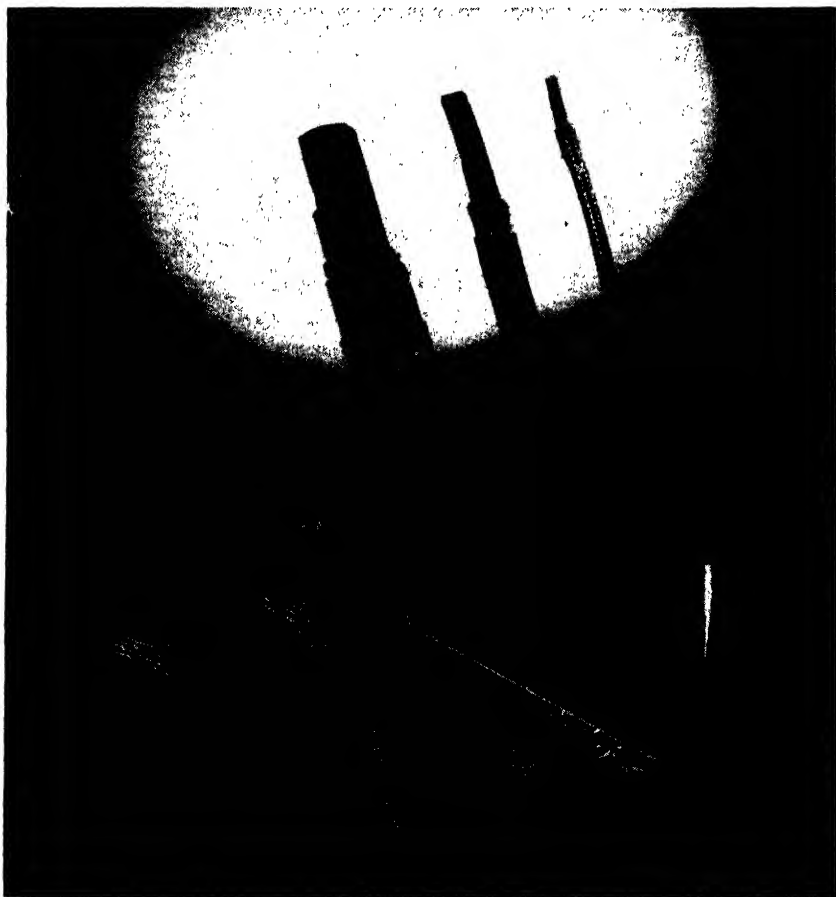
Polyethylene can be made in a number of different types varying in character depending on the manufacturing method used. Thus, it is possible to produce a series of polymers of ethylene having various average molecular weights.

The polyethylene resins are tough, flexible over a wide range of temperatures (including very low ones), translucent, and normally white in color. They possess many unusual properties, particularly excellent electrical insulation characteristics and high water resistance. The unusual combination of electrical and mechanical properties makes polyethylene suitable for the insulation of high-frequency and high-voltage equipment. The resins were first produced in quantity early in 1943 and, during the remainder of the war period, the major portion of output was used exclusively for the insulation of high-frequency wire and cable.

PROPERTIES

An outstanding property of polyethylene both as a plastic and as a filament is its low specific gravity, which is 0.92. It is not only lighter than other textile materials, but it is also lighter than water, and a rope made of the filament will float in water. The table shows the specific gravity of polyethylene compared with other textile fibers, (see page 134).

Polyethylene has unusual solubility characteristics. It is insoluble in all organic solvents at ordinary room temperatures. However, it begins to dissolve in a number of organic solvents



Courtesy Bakelite Corporation

FIG. 32. Polyethylene has many uses for plastics as well as for fabrics. Its first important application was made during the war for wire insulation.

at a temperature from 50° to 60° C. (122° to 140° F.). Typical and effective solvents for polyethylene at such temperatures are carbon tetrachloride, toluene, xylene and trichloroethane. In addition, it has unusual water resistance.

Another important advantage of polyethylene filament is that it possesses excellent color fastness. This is evident from fadeometer tests. The filaments may be made in an unlimited range of color, both translucent and opaque.

Specific Gravity

Polyethylene	0.92
Nylon	1.14
Silk (degummed)	1.25
Acetate rayon	1.32
Wool	1.32
Vinyl resin (Vinyon)	1.35
Flax	1.50
Viscose rayon	1.52
Ramie	1.52
Cotton	1.54
Vinylidene chloride	1.72

Polyethylene has a waxy "hand." The material has a high extensibility and a property described as "elasticity with a lazy recovery." It also has excellent low temperature flexibility and is quite stable at ordinary temperatures. However, it loses strength at elevated temperatures and becomes soft.

Polyethylene has a fusing and melting point of 230° F. (110° C.), which is definitely above the boiling point of water. It is possible to add plasticizers to the material, but in such cases, the yield stress and tensile strength are decreased. Polyethylene is odorless at normal temperatures.

A disadvantage of polyethylene for certain applications is its inflammability. For example, polyethylene staple fiber would be too inflammable for use in wearing apparel and the like.

MONOFILAMENTS

Polyethylene monofilaments have been produced experimentally by Carbide and Carbon Chemicals Corporation by a process of dry extrusion. Then they are oriented by stretching in order to develop high strengths. Polyethylene filaments have

been produced with tensile strengths up to 35,000 or 40,000 lbs. per sq. in. and filaments as fine as 0.01 inch have been made.

The main advantages of polyethylene monofilaments are lightness and resistance to mildew. Promising applications include marine installations and halyards, as well as ropes that float, since polyethylene is not injured by remaining wet over a period of time. Other applications are filter cloths and insect screening.

TABLE 7.1. PROPERTIES OF POLYETHYLENE MONOFILAMENT

Specific gravity	0.92
Tenacity	2.7 gms./denier
Tensile strength (room temp.) ..	32,000 lbs./sq. in.
Elongation (room temp.)	20%
Tensile strength at 60° C.	19,000 lbs./sq. in.
Permanent elongation	1%
Shrinkage at 60° C.	2.6%
Shrinkage at 80° C.	5.8%
Color fastness	Excellent
Range of color	Unlimited, opaque and translucent
Electrical properties	Excellent
Flammability	Inflammable
Water resistance	Excellent
Chemical resistance	Excellent
Melting point	230° F. (110° C.)
Resistance to mildews, insects, etc.	Excellent

PATENT INFORMATION

Inasmuch as polyethylene filaments are still largely in the development stage, the best source of information is patents which have been issued both in the United States and in Great Britain. The more important patents on polyethylene filaments are summarized herewith:

U. S. 2,210,774 (August 6, 1940). "Fibers from Ethylene Polymers," assigned to Imperial Chemical Industries Limited, of Great Britain. This is the same as British Patent 472,051.

Polymers of ethylene may be prepared by subjection to pressures in excess of 500 atmospheres under controlled elevated

temperatures ranging from 100° to 400° C. (212° to 752° F.) and preferably from 150° to 250° C. (302° to 482° F.). This results in various polymers of ethylene, the molecular weights of which vary, depending particularly upon the pressure employed. By using pressures of more than 1000 atmospheres, solid polymers of ethylene can be formed.

The solid polymers so obtained have a molecular weight of at least 6000, and a melting point of from about 100° to 120° C. (212° to 248° F.), depending upon the molecular weight. They correspond substantially in composition to $(CH_2)_x$ and when subjected to x-ray diffraction analysis show a crystalline structure.

Fibers or filaments of high strength can be obtained from a polymer of relatively high molecular weight by cold drawing to bring about orientation of the molecules. Maximum orientation is obtained when the filament has been extended about five times its original length.

In a typical procedure, the ethylene polymer is melted and extruded through a number of fine holes (as in a rayon spinneret) under steady pressure. The temperature on the delivery side of the fine holes is so adjusted that the polymer solidifies shortly after its emergence. The filaments formed are collected and wound on a bobbin at such a speed that they are, to a certain extent, drawn out, thereby producing a degree of orientation in the structure. If desired, the fibers can be cold drawn in a separate operation or as an integral part of the spinning operation. The filaments or fibers may be formed into yarns for use in making knitted and woven fabrics.

For the production of staple fiber, a number of continuous filaments are collected as they are extruded from the spinneret, and wound into a hank. Then the hank is stretched in the cold and cut up into lengths of 2.5 inches to give a fluffy staple fiber. A sliver of the staple fiber may be converted, by suitable twisting and pulling operations, into a yarn for the manufacture of woven fabrics.

Polyethylene fibers are highly resistant to water and are insensitive to conditions of humidity. At ordinary temperatures

their wet strength is substantially equal to their dry strength. They are also resistant to alkalies, acids, and many other chemicals. They combine strength, elasticity, cohesion and lightness.

Polyethylene fibers are pliable and can be tied into hard knots without seriously impairing their tenacity. The elastic recovery of the fibers is such that when stretched 4% for 1 minute, they recover at least 80% of their extension in 1 minute. In another example, the fully oriented fibers, when stretched by 3%, recovered 70% of the stretch within 2 seconds.

The tensile strength of polyethylene fibers or filaments increases with the molecular weight of the initial material as may be seen from the table:

<i>Molecular Weight</i>	<i>Tensile Strength</i>	
	<i>Kg./mm.²</i>	<i>Lbs./sq. in.</i>
6,000	3.5	5,000
10,500	8.5	12,000
15,000	10.0	14,000
21,000	21.0	30,000

B. P. 565,282. This patent discusses an improvement in the method for making polyethylene filaments described in B. P. 472,051 (U. S. 2,210,774).

The method involves a stretching technique such as is used for improving other synthetic fibers—for example, nylon and Vinyon.

The polyethylene raw material having a melting point of about 250° F. (120° C.) is brought into a molten condition within the melt-chamber heated to about 600° F. (315° C.). It then drops through a sand filter and is forced by means of a metering pump through the spinneret pierced with 15 holes each of 0.007 inch in diameter.

The emerging polyethylene streams then traverse a distance of 1.5 feet before entering the vertical cell where an upward cur-

rent of cold air completes solidification of the filaments so that they can be collected together into the form of yarn. The real stretching stage in the process follows:

The freshly solidified yarn is guided downward and then passes around two drums, the first driven at a linear speed of 600 feet per minute, and the second at twice this speed before the yarn is finally wound on the bobbin. Through these operations the yarn is stretched about 100% and given the following physical properties:

Extensibility at break	.... 80 to 100%
Tenacity	..... 0.9 gm./denier
Elasticity	..... Immediate 100% recovery from strains up to 30%
	..... Immediate 50% recovery from strains up to 52%
	..... After 2 minutes, 73% recovery from strains up to 52%

The data apply to polyethylene fibers produced from resin having a molecular weight of about 15,000. By lowering the spinning rate, it is possible to make stronger fibers from polyethylene resins which have a molecular weight of about 16,000 to 18,000.

It is comparatively easy to adapt the above manufacturing process so that staple fiber is produced instead of continuous filaments.

U. S. 2,325,060 (July 27, 1943). "Nonshrinking Yarn," assigned to E. I. du Pont de Nemours & Co. This is the same as B. P. 564,584.

Completely oriented ethylene polymer filaments begin to shrink at 45° to 50° C. (113° to 122° F.). This shrinkage reduces greatly their tensile strength and leaves them in a highly nonuniform condition. Such shrinkage warps and distorts fabrics made from these filaments so completely as to reduce materially their utility. The known method of pre-shrinking filaments

made from other high molecular weight polymers, in which relaxed filaments are shrunk by heat treatment, is ineffective in the case of polyethylene filaments.

The shrinkage temperature is raised by maintaining the oriented ethylene polymer filaments at a temperature higher than the desired initial shrinkage temperature, and below the melting point (while allowing no retraction in the direction of orientation—that is, in the direction of the length of the filaments), until there is no further reduction in tension. The filaments are then heated in the relaxed condition at a temperature at least as high as the desired initial shrinkage temperature until substantially no further shrinkage occurs. The temperature selected for the conditioning depends upon the combination of shrinkage and tensile properties desired in the finished product. Higher temperatures cause a greater reduction in filament strength, but also raise proportionally their initial shrinkage temperature.

The improvement in the shrinkage characteristics of an oriented 5-filament yarn having a denier of 90, made from polyethylene resin having a molecular weight of 20,000 and a melting point of 110° C. (230° F.) is shown in the following table:

	<i>Shrinkage at 90° C. (%)</i>	<i>Initial shrinkage at about</i>	<i>Tenacity † (gms./den.)</i>	<i>Elongation (%)</i>
Original yarn	38	40° C.	3.2	10
After heat setting	6	70° C.	2.9	27
After shrinking	0	95° C.	2.2	40

† Tenacities are given in grams per denier based upon the original dimensions of the yarn.

U. S. 2,325,060 and U. S. 2,367,173 (January 9, 1945). These patents give many suggested applications for polyethylene fibers.

Polyethylene fibers and filaments are suitable for tapered or cylindrical bristles which are used, for example, in rotary brushes for cleaning filter screens, and in brushes for use in plating and pickling baths. Likewise, the filaments are useful as surgical

sutures, which can be sterilized readily by chemical means, and are inert to water, and to body fluids and tissues. The filaments are also useful as fishing leaders and their property of floating on water makes them of special value as dry-fly leaders. Many types of screens which are highly resistant to deterioration during outdoor and ultraviolet exposure can be fabricated from these filaments.

The filaments are adapted to the fabrication of such articles as fish nets, hair nets, and dental floss which is soft and flexible. They can be used as fibers in currency paper, as corrosion-resistant packing, as elastic fibers, as insulation for electrical conductors by winding the oriented fiber around the wire and then thoroughly shrinking it firmly into place by the application of heat, as windings for baseballs and golf balls, and as cords for reinforced rubber articles.

The ethylene polymer filaments are serviceable in the manufacture of yarns, metallized yarns, braided cords, ropes, and coated, impregnated, laminated, or composite fabrics. The filaments or yarns can be used alone or in admixture with other textiles such as cotton, silk, rayon, or wool and the composite material fabricated into textile fabrics such as by knitting, weaving or felting.

In making felted fabrics or artificial felt, heat is applied to the oriented fiber and the resulting shrinkage produces a felting or interlocking action. An artificial leather may be made by felting and fusing the fabric.

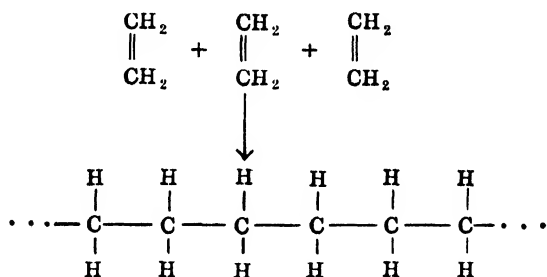
Fabrics made of the ethylene polymer filaments, because of their water resistance, durability, and elasticity, have many potential applications, among which are the following: awnings, tents, sail cloth, Holland cloth, lamp shades, flags, parachutes, gloves, camera bellows, airplane fabrics, filter cloths, corrosion-resistant packings and gaskets, aprons for trade, laboratory and surgical uses, diaphragms for gas meters and the like, balloon fabrics, blankets, garters, foundation garments, belting, hosiery, helmets, suspenders, brassieres, jackets, artificial fur, composite fabrics, carpets, rugs, and the like.

PRICE

Price of polyethylene resin (1945) is 75¢ per pound, and the spread between the resin and the monofilament is from 25¢ to 50¢, indicating a price for the monofilament of from \$1.00 to \$1.25 per pound. It is anticipated that both the resin and monofilament prices will be reduced gradually.

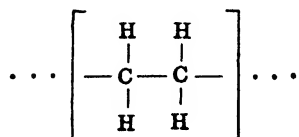
CHEMISTRY

Polyethylene is a polymer made by heating ethylene, $\text{CH}_2 = \text{CH}_2$, under high pressure so that numerous ethylene molecules simply join together to form a much larger molecular chain in the following manner:



Polyethylene

The structural unit for the polyethylene molecule can be represented as



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Courtesy The Dow Chemical Company

FIG. 33. Polyfibre fibers measure from $1/50$ of a micron to 4 microns (a micron is $1/25,000$ of an inch). An ounce of Polyfibre could reach around the world.

CHAPTER VIII

Other Synthetic Fibers

SUMMARY

In addition to the synthetic fibers discussed in the preceding chapters, there are others which are still in the development stage. These include the promising new acrylonitrile fibers, as well as those made from polyvinyl alcohol, tetrafluoroethylene polymer, and a host of other materials.

Acrylonitrile fibers are under development by a number of important companies. The fibers as a class have two noteworthy characteristics: (1) resistance to chemicals, and (2) resistance to heat. The combination of these two properties makes the fibers outstanding.

Polyvinyl alcohol fiber is somewhat unique in that it is normally water soluble and this property was utilized during the war to make parachutes for mines dropped at sea. It can also be utilized as auxiliary thread for the knitting of nylon hosiery whereby the thread can be dissolved with water.

Polyvinyl alcohol fiber can be made insoluble in water and even highly resistant to water. Because of its high wet and dry strengths and excellent resistance to microorganisms and body fluids, it is under investigation for use in making surgical sutures. It has many other possible applications.

Another synthetic fiber is based on tetrafluoroethylene polymer, a material which is inert to chemicals and highly resistant to heat and fire.

Polystyrene fiber, which was used during the war in plastics, can be drawn out into unusually fine diameters and is of possible interest to the textile industry.

ACRYLONITRILE POLYMER FIBERS

Considerable development work was carried out during the war on a new family of fibers made from acrylonitrile polymers and copolymers. Carbide and Carbon Chemicals Corporation, General Electric Company and E. I. du Pont de Nemours & Company have each developed a special type.

The type developed by Carbide and Carbon Chemicals Corporation is made from a copolymer of vinyl chloride and acrylonitrile. It is characterized by unusual resistance to corrosive chemicals, fungi, molds, insects, etc.; high electrical resistivity; excellent processing properties; high tenacity with essentially no loss in the wet state and good elastic recovery. It does not support combustion. It can be dyed readily by acetate type dyes at the boil.

General Electric Company has taken out a patent on a fiber made from a copolymer of acrylonitrile and itaconic ester. It is claimed to have a high softening point, excellent resistance to chemicals, high tensile strength and excellent pliability.

The following information on Vinyon N has been specially prepared by Carbide and Carbon Chemicals Corporation:

VINYON N

A new type of Vinyon has been developed which, while retaining all the desirable properties of the regular Vinyon, possesses greater resistance to heat and organic solvents as well as improved dyeing properties.

The basic material for Vinyon N is a special grade of resin obtained by copolymerizing vinyl chloride and acrylonitrile by a new process. The resin is dissolved in a suitable volatile solvent, the dope so obtained is spun and the formed filaments are stretched to a considerable degree at relatively high temperatures. Stabilization of the resulting filaments is then carried out in various ways, depending on the properties desired in the end product.

Vinyon N has high resistance to corrosive chemicals, as well as to fungi, molds, and insects. It also has good water resistance. It does not support combustion. It has high electrical resistivity.

Vinyon N has excellent processing properties and can be readily dyed by using cellulose acetate type dyestuffs at the boil. It has high tenacity with essentially no loss in the wet state and it possesses high elastic recovery.

A representative sample of Vinyon N yarn stabilized in an untensioned state in boiling water had a tenacity in the wet state of 4.20 grams per denier and an elongation of 30%. It showed a shrinkage in boiling water of 0.5% and in dry heat (257° F.) of 3.5%.

When Vinyon N is stabilized by another process, the tenacity is increased, the elongation decreased and the shrinkages stated above are reduced. In addition, its original solubility in a limited number of organic solvents can be controlled to any degree desired between the limits of complete solubility and complete insolubility.

TABLE 8.1. PROPERTIES OF VINYON N*

Tenacity, wet and dry	4.20 gms./denier
Tensile strength	64,500 lbs./sq. in.
Specific gravity	1.2
Elongation	30.0%
Shrinkage, in boiling water	0.5%
Shrinkage, in dry heat 125° C.	3.5 %
Chemical resistance	Excellent
Fungus, mold, insect resistance	High
Inflammability	Does not support combustion
Electrical resistivity	High
Water absorption	0.5%
Elastic recovery	Higher than regular Vinyon
Shrinking temperature	Above 100° C. up to 160° C.

* Source: Carbide and Carbon Chemicals Corp.

TABLE 8.2. EFFECT OF SPECIFIED CHEMICALS ON "VINYON" FABRICS *

Test Chemical	Per cent concentration	Per cent shrinkage at 25° C. or 77° F.		Per cent shrinkage at 50° C. or 122° F.		Per cent shrinkage at 90° C. or 194° F.	
		Fabric Vinyon	Fabric Vinyon N	Fabric Vinyon	Fabric Vinyon N	Fabric Vinyon	Fabric Vinyon N
Water	100	None	None	5.5	None	19.0	None
Chromic acid	50	None	None	5.0	5.0	19.0	7.0
Hydrobromic acid	40	None	None	None	None	20.5	3.0
Hydrochloric acid	38	None	2.5	2.5	2.5	20.5	2.5
Nitric acid	5	None	None	1.5	None	20.0	None
Nitric acid	20	None	None	6.5	None	24.5 and Brittle	4.5
Nitric acid	70	6.0	50.0	Brittle	.....	.....	.....
Phosphoric acid	5	None	None	1.5	None	20.0	None
Phosphoric acid	85	None	None	3.0	None	20.5	None
Sulfuric acid	5	None	None	None	None	19.5	None
Sulfuric acid	50	None	None	None	None	20.5	Jelly
Sulfuric acid	80	2.0	Jelly	8.0	.....	Carbonized	.....
Sulfuric acid	96	19.0	Jelly	.....	.....	.....	.....
Ammonium hydroxide	28	None	None	.....	Solvent boils below 50 degrees C.	.....	.....
Sodium hydroxide	5	None	None	4.0	None	20.0	None
Sodium hydroxide	30	None	None	2.0	None	21.0	1.5
Sodium hydroxide	50	None	None	2.0	None	30.0	1.5
Calcium chloride	50	None	None	4.5	None	21.0	None
Ferric chloride	50	None	None	2.0	None	20.0	None

* Source: Carbide and Carbon Chemicals Corp.

TABLE 8.2.—Continued

Test Chemical	Per cent concentration	Per cent shrinkage at 25° C. or 77° F.		Per cent shrinkage at 50° C. or 122° F.		Per cent shrinkage at 90° C. or 194° F.	
		Fabric Vinyon	Fabric Vinyon N	Fabric Vinyon	Fabric Vinyon N	Fabric Vinyon	Fabric Vinyon N
Silver nitrate	20	None	None	2.0	None	19.5	5.0 and Brittle
Sodium bisulfate	50	None	None	None	None	19.0	None
Sodium bichromate	50	None	None	None	None	19.0	None
Zinc chloride	50	None	None	None	None	19.5	None
Acetic acid	100	15.5	None	18.5	None	.....	8.5
Acetic acid	90	4.5	None	18.0	None	.....	9.0
Acetic acid	80	2.5	None	18.0	None	.....	5.0
Acetic acid	50	2.0	None	12.5	None	.....	4.5
Oleic acid	100	None	None	3.0	None	19.5	None
Oxalic acid	25	None	None	None	None	19.5	4.0
Phenol	5	7.0	3.0	17.5	7.5	.....	.....
Phenol .....	.05	None	None	None	None	19.5	2.0
Acetic anhydride	100	19.0	1.5	21.0	8.5	.....	.....
Acetyl chloride	100	Destroyed	5.0	.....	.....	Boils below 90° C.	.....
Carbon tetrachloride	100	9.0	None	15.0	None	.....	.....
Chloroform	100	Dissolved	None	.....	10.0	.....	.....
Cyclohexanone	100	Dissolved	Dissolved	.....	.....	.....	.....
Formaldehyde	40	None	None	2.5	None	19.0	1.5
Methyl ethyl ketone	100	Dissolved	4.0	.....	Dissolved	.....	.....
Methyl isobutyl ketone	100	Dissolved	None	.....	None	.....	7.0
Trichlorethylene	100	13.5	None	19.0	None	Boils below 90° C.	.....
Stoddard solvent	100	None	None	2.5	None	17.5	1.5

The potential applications of Vinyon N include all those for the regular Vinyon, and the list is extended by virtue of its improved dimensional stability at higher temperatures, its improved dyeing properties, and its greater resistance to solvents.

Hosiery, full-fashioned and boarded-to-shape seamless types, is a definite end use for the yarn. Other products include industrial filter fabric, tape and braid for electrical insulation, tent fabric of various weights, protective clothing, netting, shoe fabric, marine lines and twines, surgical sutures, fishing line, dental floss, sewing thread, sailcloth, awnings, upholstery and umbrella fabric, chemical resistant hose, gasket packing, and various other products.

PATENT INFORMATION

British patent pending 15,917/44 (August 1944), "Process and Apparatus for Heat-Treating and Stretching Untwisted Yarn Consisting Essentially of a Polymer of Acrylonitrile" has been applied for by E. I. du Pont de Nemours & Co.

This is a method for increasing the tenacity of a yarn consisting of a polymer of acrylonitrile, by plasticizing and stretching the yarn without causing the filaments to adhere to each other.

In one example, a 440 denier, 40 filament, no twist yarn prepared by dry spinning a solution of acrylonitrile polymer of 103,000 average molecular weight dissolved in dimethyl formamide, was passed through a spring-leaf filament spreading device and around a hot roll. The yarn was fed on to a heated roll at the rate of 145 inches per minute and drawn from this roll at the rate of 1,450 inches per minute, thereby stretching the yarn ten times. The temperature to which the roll was heated was 165° to 180° C.

The unstretched yarn of 440 denier showed a tenacity of 0.6 gram per denier. The stretched yarn was of 42 to 45 denier and showed a tenacity of 4.3 grams per denier.

U. S. 2,366,495 (January 2, 1945), "Synthetic Products having Molecularly Oriented Structure," is assigned to General Electric Company.

This is a method for forming a synthetic fiber composed of a molecularly oriented copolymer of acrylonitrile and an ester of itaconic acid, such as diethyl itaconate or dimethyl itaconate.

All copolymers containing these two components are not susceptible to molecular orientation. However, if copolymers containing from 50 to 80% acrylonitrile and 50 to 20% of the ester are prepared, the composition obtained may be formed into filaments by extrusion or precipitation methods. Such filaments may be cold drawn to yield molecularly oriented bodies having highly increased strength and flexibility. These oriented filaments exhibit the characteristic crystalline x-ray diffraction pattern.

Acrylonitrile and its copolymers with esters of itaconic acids possess outstanding properties which make them very desirable for use as fibers. They have high tensile strength of the order of 40,000 to 50,000 lbs. per sq. in. and excellent pliability as seen by the fact that they may be tied into tight knots without breaking. Also, they have a very high softening point and excellent resistance to the action of solvents.

The preferred method for forming the oriented fibers involves first the copolymerization of the monomers. This may be accomplished by any suitable means. Two satisfactory methods involve the use of an emulsion and of mass polymerization. The latter method may be carried out by heating the monomeric mixture containing the polymerization catalyst (benzoyl peroxide) in an autoclave. As the polymerization proceeds the temperature may be increased as the vapor pressure of the mass decreases. The copolymers are freed of easily vaporizable materials, for example, monomer, low molecular weight polymers, etc., by any suitable method (for example, by sheeting with resultant evaporation or by the use of selective solvents). The polymer is then heated to some temperature above the softening point, for example, 15° to 25° C. above; extruded, and rapidly cooled. The fibers are cold drawn at this point from 100 to 200% of their original length, causing the molecules to orient them-

selves parallel to the direction of the cold drawing. The increase in tensile strength and flexibility following this operation is remarkable.

The two component systems described may be satisfactorily used to form copolymers for cold drawing into molecularly oriented fibers, but three component systems may also be used. One example of the latter is the following: 70% by weight acrylonitrile, 25% dibutyl itaconate, and 5% diethyl itaconate. Another three component system is a mixture comprising acrylonitrile, an itaconic ester, and an acrylic ester. One example is a polymerizable mass containing 70% by weight acrylonitrile, 20% ethyl acrylate, and 10% dibutyl itaconate, from which molecularly oriented fibers can be formed.

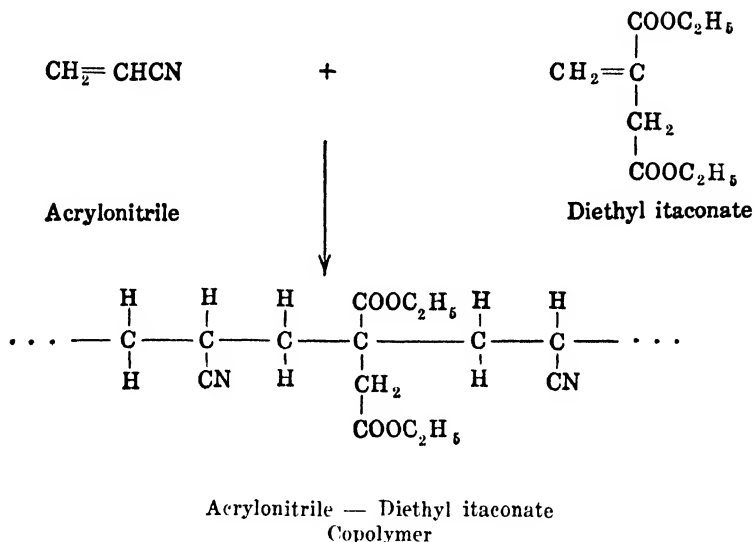
The fibers produced according to the foregoing description may be woven into highly insoluble and chemical resistant cloth for use as filter cloths in handling chemicals and the like. They may also be used for textiles; for example, hosiery, cloth, etc. It is claimed that the textile materials made from these fibers are superior to silk, cotton, linen, wool or rayon from the standpoint of their resistance to water, chemicals and solvents. They are also lighter in weight and are said to be considerably tougher and more flexible than the recently developed glass fabrics.

CHEMISTRY

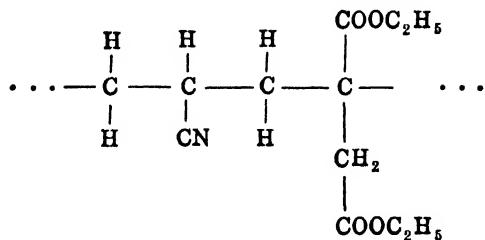
Acrylonitrile—Itaconic Acid Ester Copolymers. Copolymers of acrylonitrile and esters of itaconic acid can be cold drawn into molecularly oriented fibers. These copolymers contain from 50 to 80% acrylonitrile and 50 to 20% of the ester. Esters of itaconic acid which are especially suitable for this purpose are:

Diethyl itaconate
Dibutyl itaconate
Dimethyl itaconate
Dipropyl itaconate
Diphenyl itaconate

Acrylonitrile and diethyl itaconate copolymerize, under suitable conditions, to form a straight-chain copolymer of high molecular weight:

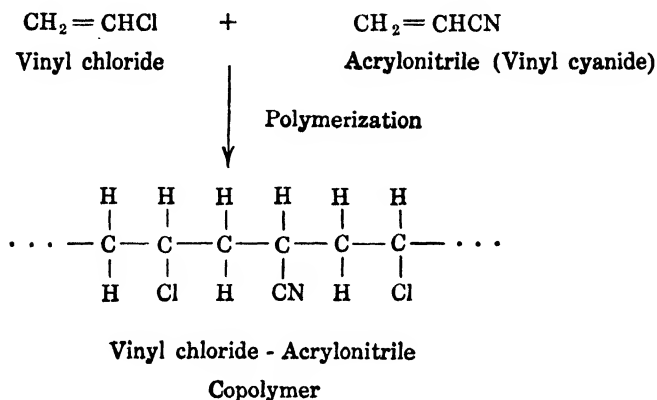


The structural unit for the acrylonitrile-diethyl itaconate copolymer is:

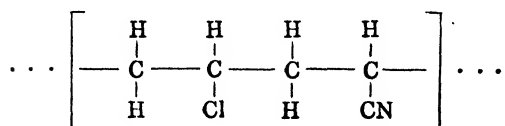


Other fiber-forming copolymers of acrylonitrile may contain mixed esters of itaconic acid. An example of such a three-component system is: a copolymer of 70% acrylonitrile, 10% diphenyl itaconate and 20% diethyl itaconate.

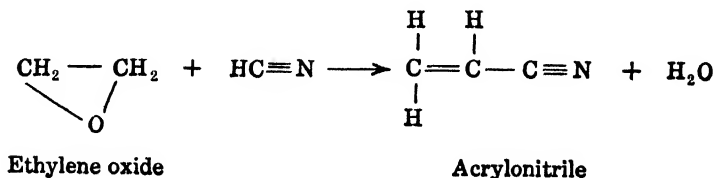
Vinyl Chloride—Acrylonitrile Copolymer. The vinyl resins used for making Vinyon N are copolymers of vinyl chloride and acrylonitrile:



The vinyl chloride-acrylonitrile copolymer is a straight-chain compound having a recurring structural unit:



Acrylonitrile can be prepared from:



POLYVINYL ALCOHOL FIBERS

U. S. 2,169,250 and U. S. 2,236,061 patents were applied for in May 1937 and issued August 15, 1939, and March 25, 1941, respectively, to E. I. du Pont de Nemours & Co.

Polyvinyl alcohol is characterized by several unique properties. It is extremely tough, flexible, and transparent and has very high elongation. However, it has several distinct disadvantages, notably its low resistance to water and its complete solubility in hot water. Nevertheless, it is extremely useful to be able to cast a film from a water solution.

Although articles of varying degrees of solubility have been produced by reacting polyvinyl alcohol with various materials such as formaldehyde, this treatment has the disadvantage that the resulting film, while insoluble in water, is still soluble in many organic solvents. Furthermore, it requires an additional step in treatment and the employment of a reagent after the film is formed.

A process has been devised to form films, threads, and the like from polyvinyl alcohol compositions in such a way that the ultimate product is insoluble in hot and cold water and in all common solvents. Such films are formed without any chemical after-treatment other than the employment of heat.

The process consists of forming a solution of polyvinyl alcohol and a compound capable of forming a cross-linked structure with polyvinyl alcohol. By further reaction, the complex molecule can be built up to form a very long-chain structure comprising a number of polyvinyl alcohol units linked together by a number of units of the compound capable of forming a cross-linked structure. For this purpose any one of a number of compounds may be used, such as methacrylic acid monomer or dimethylolurea resin.

Any type of polyvinyl alcohol of any viscosity, such as 15 to 75 centipoises (preferably 18 to 40 centipoises in 4% solution at 68° F.) may be used. Polyvinyl alcohol is generally produced by hydrolysis of polyvinyl acetate and either completely or partly hydrolyzed products may be employed. If only partly hydrolyzed products are used, the quantity of unsaponified ester and/or acetal type group must be small enough so that the product will still be soluble in hot water. Substituted polyvinyl alcohols such as polymethyl vinyl alcohol also may be used.

The compositions are converted into threads or films according to established procedure. They may be cast or spun into a suitable atmosphere to evaporate the solvent water or into a suitable coagulating bath. In either method, they may be cast continuously or discontinuously. In the continuous method of casting or spinning, the film or thread-forming composition is led into an evaporative atmosphere and then conducted, if necessary, through various treating baths.

The polyvinyl alcohol may be reacted with the cross-linking compound at any suitable stage during or after the film, thread or the like is actually formed. It may be heated before or after washing or other treatment.

This method has the distinct advantage of enabling films, threads, and the like to be cast from water solution while at the same time they may be readily insolubilized to water and most organic and inorganic solvents simply and effectively, such as by heating at a moderately elevated temperature. For example, they are insoluble in chloroform, dioxane, benzene, toluene, alcohol, ethyl acetate, acetone, or mixtures of these materials.

B. P. 563,960 (September 7, 1944) assigned to British Celanese Limited.

In this method, artificial filaments which are soluble in water are produced by spinning suitable polyvinyl compounds which are soluble in water.

Polyvinyl alcohol yarns (ester group content between 2 and 12%) may be employed for the production of fabrics and may constitute either the whole of such fabrics or may form only part thereof. For example, they may be used as weft in conjunction with a warp made of acetone-soluble cellulose acetate. These fabrics, which dissolve or disperse in water, are very useful for the production of parachutes for mines to be laid in rivers or the sea, since after the mines have been laid the parachute becomes substantially invisible and does not reveal the presence of the mine. Such fabrics may be dyed a suitable shade in order to render the parachute inconspicuous before it dissolves; for in-

stance, by introducing a dyestuff into the spinning solution from which the yarns are produced.

British patent pending 6487/44 (April 1944), "Improvements in and relating to polyvinyl alcohol filaments," has been applied for by Johnson & Johnson (Great Britain) Limited.

This patent relates mainly to improvement in polyvinyl alcohol filaments so that they are suitable for use as surgical sutures.

Being inert to body fluids, it has been proposed heretofore to use polyvinyl alcohol filaments as a substitute for catgut and silk because sutures made of such materials are often accompanied by stitch abscesses and tissue inflammation. However, polyvinyl alcohol sutures made in accordance with such prior processes are unsatisfactory because of their inability to meet the strength requirements of a good suture, or to retain their strength in the presence of the tissue fluids.

A prerequisite for a good suture is high wet strength. High wet strength is not synonymous with water resistance, but, on the contrary, refers to the strength of the filament after it has had an opportunity of soaking up water. The filaments should become pliable in water without excessive elongation, shortening, or change in thickness. Furthermore, after soaking in water or in the body fluids for one or several days, the filaments should possess adequate strength to resist any strain that body tissues may impose and should not become elastic so as to cause constriction or continuing strain on the tissues. By way of comparison, catgut of good quality exhibits a wet to dry strength ratio of 0.5 which is adequate. On the other hand, a filament made of polyvinyl alcohol by prior methods exhibits a wet to dry strength ratio of 0.2 or less. Such a ratio of wet to dry strength is entirely inadequate for suture use.

The improved polyvinyl alcohol filaments are claimed to have a tenacity as high as 5 grams per denier when dry and 3 grams per denier when wet, which is a wet to dry strength ratio of 0.6. When it is considered that, for material of the specific gravity of polyvinyl alcohol, 1 gram per denier is equivalent

to a tensile strength of 18,000 lbs. per sq. in., a filament possessing a tensile strength of 90,000 lbs. per sq. in. when dry and 54,000 lbs. per sq. in. when wet (i.e., after soaking at least 24 hours in water) has advantages which are manifest.

It has been found possible to control the wet strength of polyvinyl alcohol filaments through the medium of a heat-treating process, the critical factor of which is the moisture content of the polyvinyl alcohol during the period of heating. To be more specific, the filament is first extruded, properly conditioned for stretching, and then stretched to give proper orientation of the molecules. Thereafter, the stretched filament is adjusted to a given moisture content and then heated under conditions which maintain the moisture content substantially intact or at least prevent the escape of too much water. With this procedure, filaments may be produced having high tensile strength and a high wet to dry strength ratio, the tensile strength and wet to dry strength ratio depending upon the moisture entrapped in the filaments during the heat-conditioning step.

The best results have been obtained where the moisture content during the heat-conditioning process is between 6 and 12%.

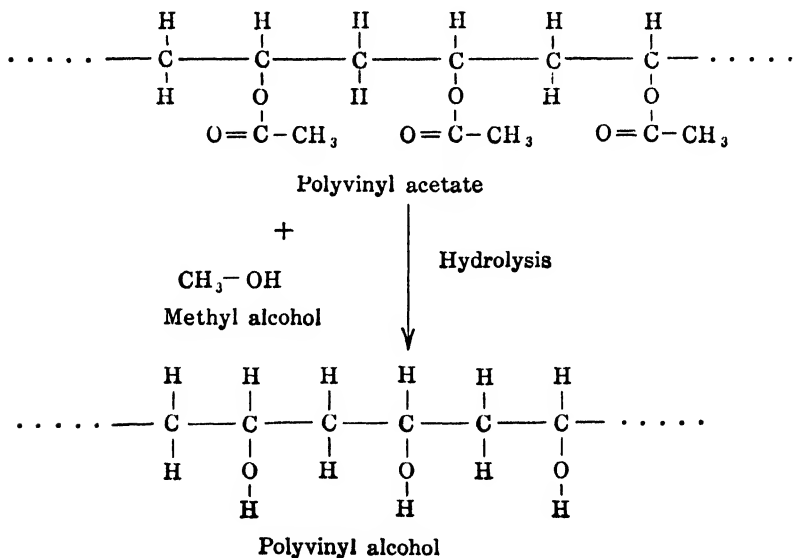
Sulfonamides, such as sulfanilamide up to 5%, may be incorporated into the spinning material without any appreciable detriment in the tensile strength of the finished filament. The sulfonamide carried into the suture tract by a polyvinyl alcohol suture will act to inhibit the growth of bacteria in the suture tract and thus assist in the prevention of stitch abscesses.

Polyvinyl alcohol strands in very large sizes may be used for tennis racket strings, in which the monofilaments may be grouped into bundles and coated with a polyvinyl alcohol size prior to the stretching process and the stretched strand heat treated.

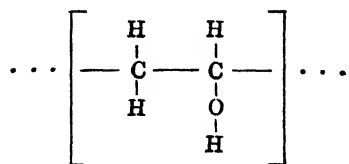
British Patent 566,507 describes the use of polyvinyl alcohol thread as an auxiliary thread in the knitting of women's nylon hose to give them better fitting qualities. The auxiliary thread is considerably thicker than the nylon thread, and thus gives bulkiness to the knitted stocking. This would not be possible by any simple adjustment of the knitting machine. Since the poly-

vinyl alcohol thread is in the water-soluble form, it can be removed later by treating the knitted stocking with water.

Chemistry. Polyvinyl alcohol can be obtained by the catalytic hydrolysis of polymerized vinyl esters or other hydrolyzable polymerized vinyl compounds. According to this method, a solution of a polymerized vinyl compound is reacted with an alcohol in the presence of a small amount of an alkali as a hydrolysis catalyst. Starting, for example, with polymerized vinyl acetate and methyl alcohol, the products of the reaction are polyvinyl alcohol and methyl acetate. This reaction can be represented by the structural formulas as follows:

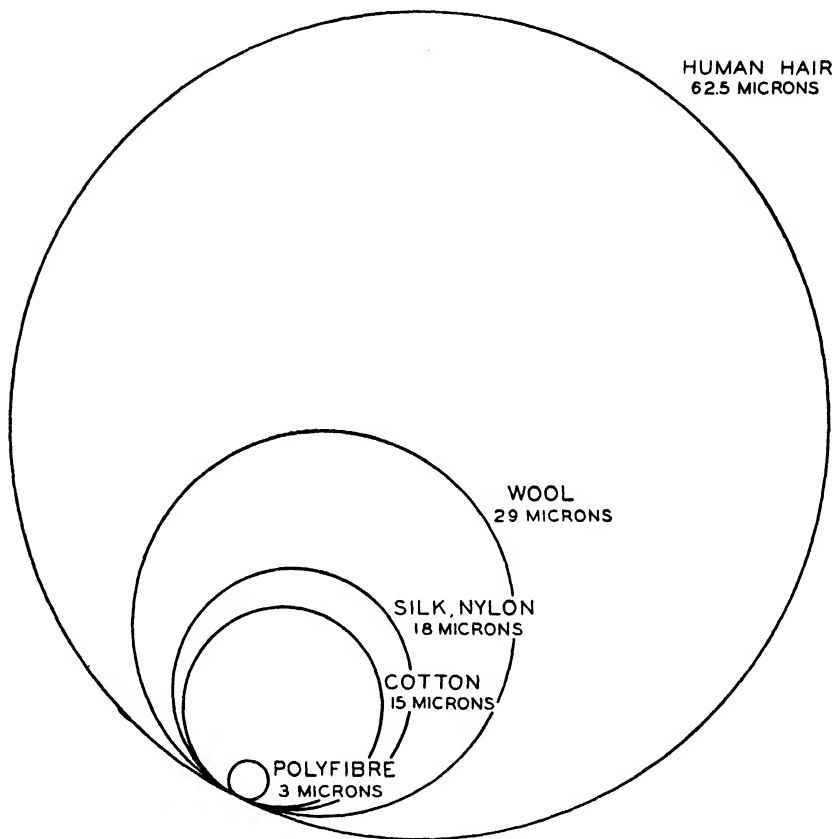


The structural unit for polyvinyl alcohol is:



POLYSTYRENE FIBER (POLYFIBRE)

"Polyfibre" is the name of a new fiber made from polystyrene, developed by The Dow Chemical Company and announced in 1944. It is a fiber ranging in size up to 4 microns



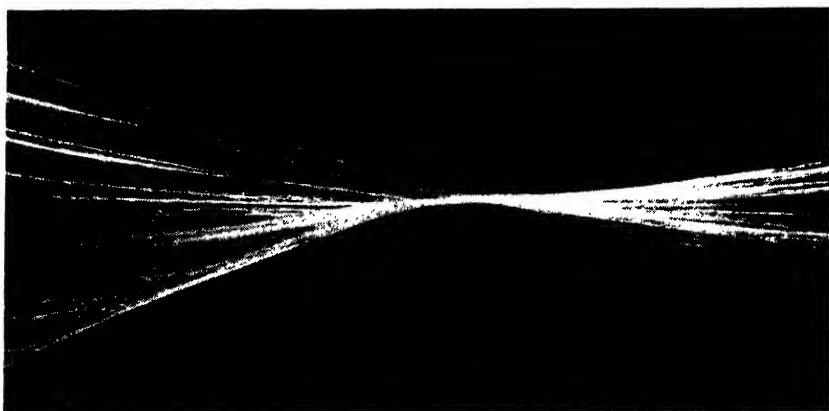
Courtesy The Dow Chemical Company

FIG. 34. Polyfibre compared to typical sizes of other fibers. Although shown at 3 microns, Polyfibre filaments range in size from $1/50$ of a micron to 4 microns.

in diameter. A comparison of this extremely fine fiber size with some of the more familiar natural fibers is shown in Figure 34. A high degree of orientation exists in Polyfibre. This orientation is relieved when the fiber is heated and shrinkage results, which exerts considerable force.

When first introduced, Polyfibre was supplied in its simplest form as a bat of parallel fibers running crosswise of the bat. The bat width was approximately 14 inches and its length approximately 10 feet. In this form, Polyfibre has an apparent density of about 0.05. A bat of this type was used during the war in the fabrication of plastics, but other commercial forms of the material are under consideration.

While Polyfibre was designed primarily for further heat fabrication, it has in itself some interesting properties as a fiber.



Courtesy The Dow Chemical Company

FIG. 35. Polyfibre filaments.

Inasmuch as the bat is composed of extremely fine fibers, it contains many minute air spaces. For this reason it provides good low-temperature thermal insulation.

In addition to being an excellent thermal insulating material at low temperatures, Polyfibre appears to be one of the best sound insulating media. Theoretically, this is to be expected inasmuch as the slightly compacted fiber bat contains a multitude of interconnected air paths. These relatively long paths offer the best possible channels in which sound waves may dissipate their energy.

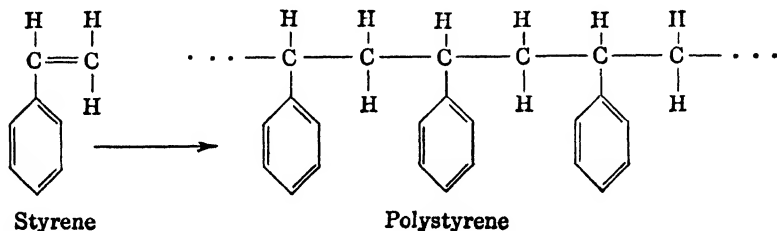
Polystyrene is difficult to wet and this property is inherent in Polyfibre. This suggests the possibility of using Polyfibre as a replacement for kapok in applications requiring buoyancy.

Such applications might include floats, lifevests, and emergency rescue equipment.

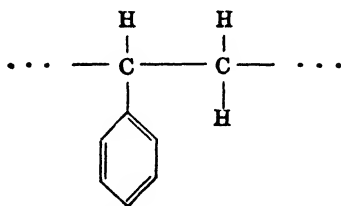
Polystyrene fiber (Polyfibre) will perhaps be used in such fabrics as: felts, shoe liners, cloths, carpeting and padding. As to its use in apparel fabrics, there is nothing as yet to report.

An interesting fact in connection with Polyfibre is that it is not made in the conventional way involving the use of a spinneret. The fiber is drawn out from the molten mass in extremely fine diameters (U. S. Patent 2,385,358).

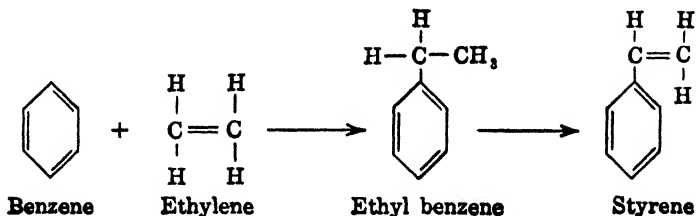
Chemistry. Polystyrene is an aromatic vinyl compound which can be produced by polymerizing styrene under suitable conditions:



The structural unit for polystyrene can be represented as follows:



Styrene, a very reactive unsaturated hydrocarbon, can be prepared from benzene and ethylene:



TETRAFLUOROETHYLENE POLYMER FIBER

A fiber can be made from a polymer of tetrafluoroethylene, a new plastics material developed by E. I. du Pont de Nemours & Co.

The polymers of tetrafluoroethylene are white or brown powders or jellies, which are insoluble in the usual solvents and inert to the usual chemical reagents. These polymers become incandescent in the presence of a flame, but do not burn when the flame is removed, and melt only at red heat. They are insoluble in hot or cold water, acetone, ether, petroleum ether, ethyl alcohol, iso-amyl alcohol, carbon tetrachloride, $C_2F_3Cl_3$, dichlorobenzene, ethyl acetate, pyridine, nitrobenzene, 30% sodium hydroxide, petroleum oil, glacial acetic acid, concentrated sulfuric acid, and concentrated nitric acid.

The inertness of the polymer to chemical reagents, its insolubility, and its resistance to heat and to fire make it useful in many applications. In addition to its uses in molded plastics, the material can be extruded into fibers for use in the manufacture of heat-resistant clothing and the like.

Tetrafluoroethylene polymer has a solid phase transition temperature of $620^\circ F.$, above which there is disorientation, loss of crystalline structure, and a drop in strength. The density varies from 2.1 to 2.2.

Chemistry. Polymers of tetrafluoroethylene can be prepared by polymerizing tetrafluoroethylene, $CF_2=CF_2$, under high pressure in the presence of a catalyst:

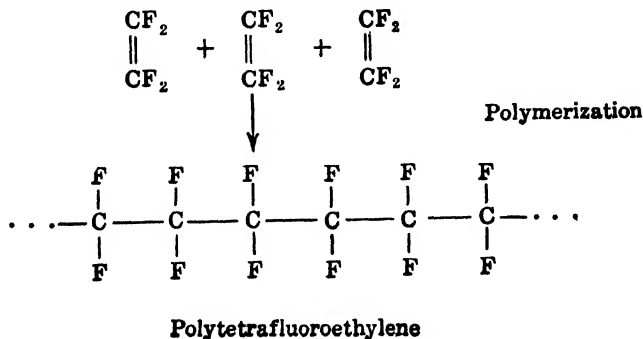


TABLE 8.3. PROPERTIES OF "FIBER A"

Polymethacrylonitrile

Tensile strength, dry	60,000 to 75,000 lbs./sq.in.
Tensile strength, wet	57,000 to 70,000 lbs./sq.in.
Tenacity, dry	4.0 to 5.0 gms./denier
Tenacity, wet	3.8 to 4.7 gms./denier
Tenacity, loop	3.4 to 4.2 gms./denier
Elongation, dry	14 to 22%
Elongation, wet	14 to 21%
Elongation, loop	10 to 18%
Specific gravity	1.17
Elastic recovery, from 2% stretch ..	100%
Elastic recovery, from 4% stretch ...	67%
Moisture regain, 60% R. H.	0.9 to 2.0%
Water absorption	3%
Shrinkage in water at 100° C.	None
Burning rate	Between that of cellulose and cellulose acetate
Sticking temperature	190° to 220° C. (374° to 428° F.)
Discoloration on heating	Yellow on prolonged heating at 110° C. (230° F.)
Effect of light	Highly resistant
Effect of microorganisms and insects.	Highly resistant
Effect of chemicals	Highly resistant
Dyeing properties	Poor (may be dyed with cellulose acetate type dyestuffs)
Flex life	19,000
Abrasion resistance of 1.5 oz. fabrics	366 revolutions (about the same (Taber) as cotton)
Shape of cross section	Dog bone and varied
Yarn sizes	40 to 600 denier, 3 denier per filament

POLYVINYL CHLORIDE FIBERS

The B. F. Goodrich Company did some experimental work in 1943 on polyvinyl chloride monofilaments from which to weave insect screens. The company reports that such screens

"are in actual service tests and so far are giving an entirely satisfactory account of themselves."

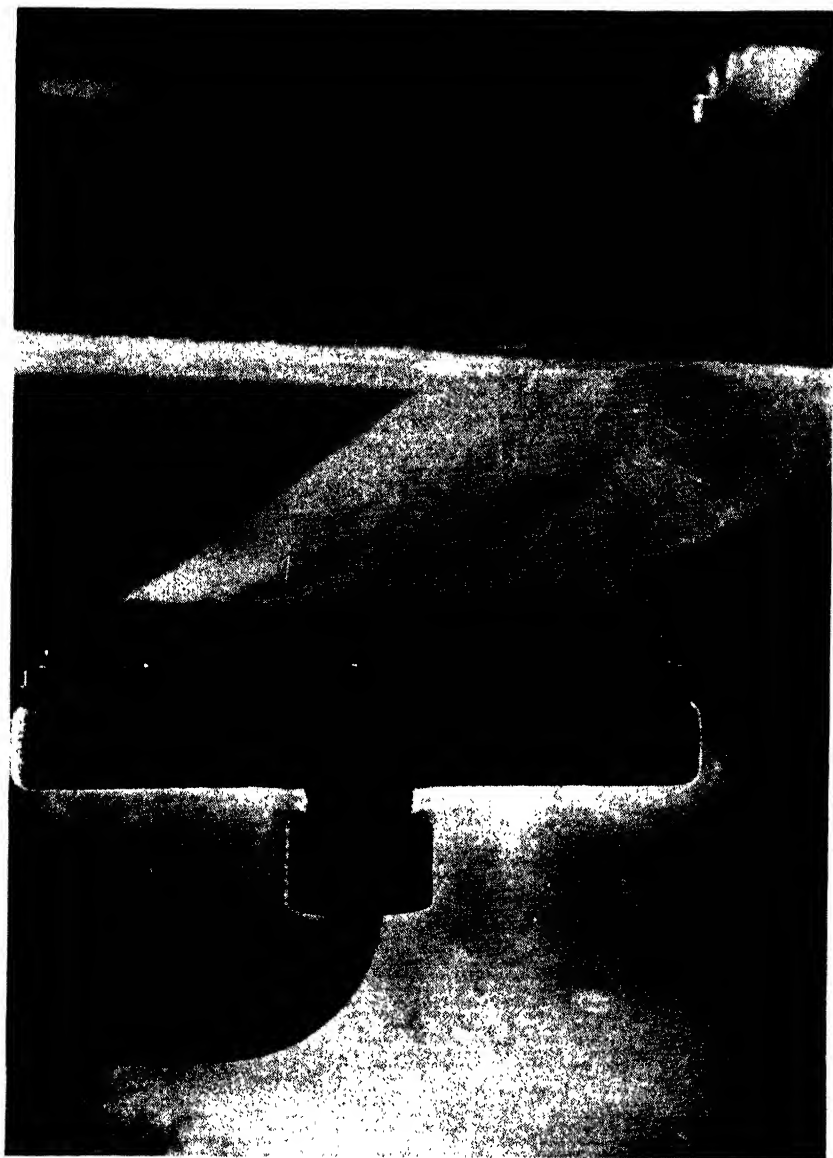
However, development work on polyvinyl chloride filaments was suspended by the company during the war. There are still problems to be ironed out in connection with polyvinyl chloride filaments, particularly as regards shrinkage.

STYRENE COPOLYMER FIBERS

Standard Oil Company (New Jersey) has developed a series of new styrene-type copolymers having rubbery to resinous properties. These copolymers can be extruded as monofilaments and oriented. Tensile strengths up to 15,000 or 20,000 lbs. per sq. in. have been reached. The critical temperature is from 60° to 80° C. The polymers have good resistance to dilute and concentrated acids and alkalies, but lack grease resistance.

REFERENCE

1. "Polyfibre—A New Approach to Plastic Molding," W. C. Goggin and R. R. Bradshaw, The Dow Chemical Co., Plastics Development Div., Midland, Mich., May 1944.



Courtesy Aralac, Inc.

FIG. 36. This shows Aralac fiber as it comes out of the spinneret. Liquefied casein enters the spinneret through the pipe, lower left, and under pressure is forced through thousands of holes in the spinneret. The white "tape" at the top actually contains thousands of strands of fiber.

CHAPTER IX

Casein Fiber

SUMMARY

Unlike the synthetic fibers which have been developed in recent years, the protein fibers now in commercial production do not have any marked advantages in properties over the natural fibers. The principal advantage of the protein fibers is one of price.

Casein fiber, first of the protein fibers to be produced commercially and utilizing skim milk as a raw material, is much cheaper than wool. It is comparable with wool in its appearance, warmth-retaining qualities and ability to absorb moisture without feeling damp and clammy. It is also fairly similar to wool chemically and can be dyed with the same kind of dyes.

However, casein fiber is less elastic and not so crease-resistant as wool, and its surface structure is such that it possesses less clinging power. Its dry strength is lower than that of wool and its wet strength so inferior as to constitute its principal disadvantage.

The bulk of output of casein fiber (now around 9,000,000 lbs. a year) has been used for blending with rayon, cotton, wool and fur. It imparts wool-like characteristics to fabrics containing rayon or cotton and serves as an inexpensive substitute for wool or fur.

The proportion of casein fiber in blends has been increasing from year to year. New types of casein fiber have been developed that are finer than wool.

HISTORY AND DEVELOPMENT

It was long ago suggested that it should be possible to produce an artificial fiber, which would have the properties of wool as a clothing material, since wool has been one of the most valuable materials available for clothing. The easiest way to produce such a fiber is to start from casein, a protein which can be readily obtained in a pure state. This is one of the reasons why casein was chosen as a raw material.

An artificial fiber produced from casein must compete to some extent with wool. It will naturally be compared with wool and its merits will be judged partly on the basis of such a comparison.

It is possible to manufacture casein fibers that will equal and even surpass wool with regard to staple length and fineness. Moreover, casein fibers have the advantage of greater uniformity of properties.

Many attempts have been made to produce from casein a fiber suitable for textile purposes. As early as 1904, a German chemist named Todtenhaupt applied for patents covering a fiber made from casein. Apparently, none of the processes proved practical. It was not until 1935 that the Italian chemist, Antonio Ferretti, developed a practical method for producing a casein base fiber having properties which would make it suitable for textile purposes. In Italy, this new fiber, called Lanital, aroused considerable interest, and in a short time became of national importance as a substitute and diluent for wool. Many countries, including England, Japan, and Germany, developed casein and other protein base fibers to which they gave various trade names. Interest in a casein fiber with wool-like properties was renewed during the war because of the shortage of wool.

In the United States, considerable research and development on casein fibers were carried out by the United States Department of Agriculture and by National Dairy Products Corporation in an effort to find new markets for skimmed milk. As a result of this work, Aralac, the first fiber from a natural protein base to be produced commercially in the United States, was introduced by National Dairy Products Corporation in 1939.

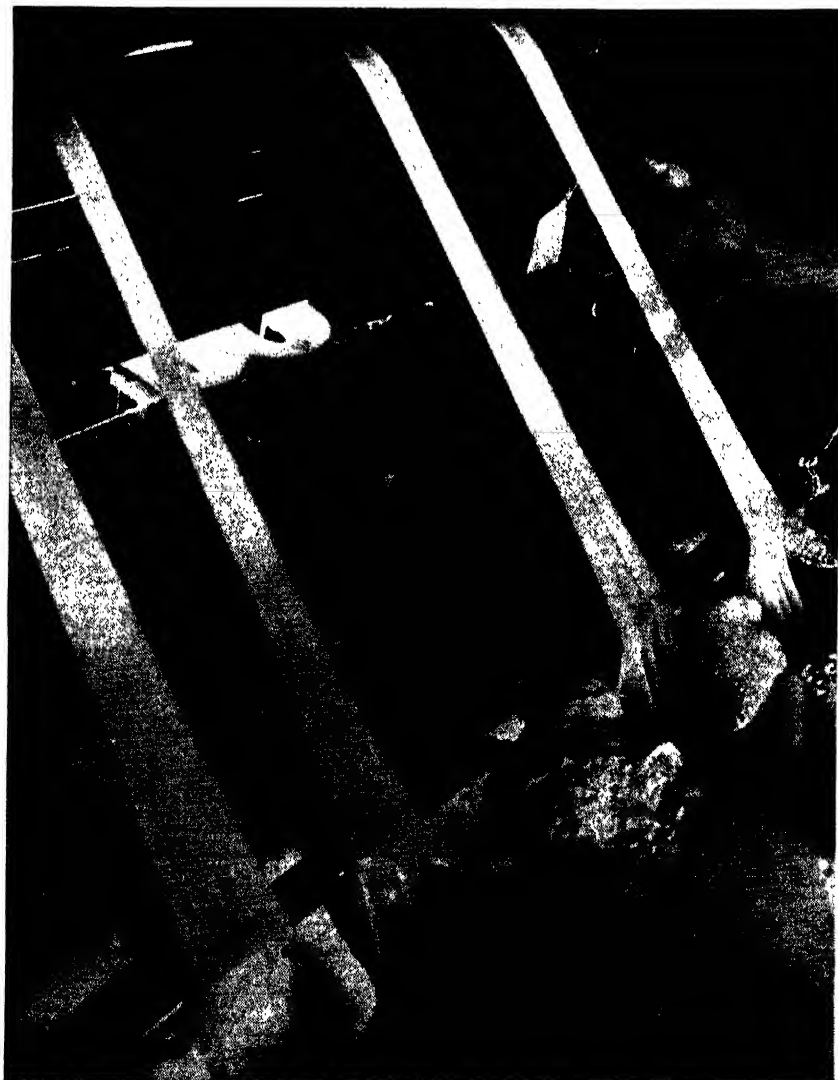
MANUFACTURE OF ARALAC

The basic material for Aralac is casein, obtained by the addition of acid to skim milk under controlled conditions. The curd thus formed is washed and then dried. A concentrated solution of the casein, prepared by dissolving it in water by means of an alkali, is forced through spinnerets into an acid bath which contains various salts, such as those of aluminum and zinc. This treatment solidifies the streams of casein solution into filaments which are then carried into other baths to make them more resistant to acids, alkalies, and the high temperatures which may be subsequently used in scouring and dyeing operations. The fibers are then washed, dried, and cut to any desired length.

Patents issued to F. C. Atwood and assigned to National Dairy Products Corporation reveal in detail processes for the production of casein fiber. Some of the important points are (1) very low alkalinity of spinning solution, corresponding to a pH of 7 and about 2 grams of sodium hydroxide per 100 grams of casein, (2) a short procedure for dispersing acid or rennet casein with the aid of heat, (3) a continuous method for treating with formaldehyde, and (4) acetylation with ketene or acetic anhydride.

Most of the Aralac which goes into yarns is blended with other fibers. In such cases, a predetermined amount of Aralac together with a quantity of rayon, wool, or cotton staple, or a combination of any of these, is placed in the blending room. The fibers are then thoroughly mixed by a machine known as the picker. Then the mixed fibers are drawn into strands which are continuously combed, twisted into rope-like lengths, then combed out again and twisted into lengths of progressively decreasing thickness or diameter until there is a fine strand of blended yarn. Such a strand is actually a uniform mixture of Aralac and other fibers. This single strand may be used for weaving, or it may be plied—that is, twisted together with other yarns—before it is put in the looms.

Actual construction of the cloth is controlled by the looms at the weaving mill. When the cloth is woven, it is known as greige (or grey) goods (fabrics just off the loom or knitting



Courtesy Aralac, Inc

FIG. 37. Concealed under the foam are four spinnerets. The four taffy-like strips are Aralac fibers in one of the first stages of processing.

machine and in an unfinished state). The finishing is usually done by a converting house which dyes the fabric and gives it a final finish before it is sold to the garment manufacturer.

PROPERTIES

Aralac is soft and feels somewhat like wool. Under the microscope, it presents a smooth surface similar to rayon, as contrasted with the scaly surface of wool.

It is available in various fiber sizes, the most popular being those which correspond to 50's, 60's, and 70's wool (equivalent to 7, 5, and 3 denier rayon). It is also offered in staple lengths from 0.5 to 6 inches.

The tenacity of Aralac varies from 0.6 to 0.8 grams per denier in the dry state; whereas in the wet state, the tenacity is about 0.4 grams per denier. Its tensile strength is approximately 10,000 to 13,000 lbs. per sq. in.

CHEMICAL COMPOSITION OF ARALAC, LANITAL, AND WOOL*

<i>Elements</i>	<i>Aralac</i> %	<i>Lanital</i> %	<i>Wool</i> %
Carbon	51.23	53.0	49.25
Hydrogen	7.01	7.0	7.57
Oxygen	26.93	23.0	23.66
Nitrogen	13.29	15.5	15.86
Sulfur	0.72	0.7	3.66
Phosphorus	0.82	.....	.....
	100.0	99.2	100.0

* Source: "The Processing of Aralac and Other Protein Base Fibers," H. E. Millson, *Calco Technical Bulletin No. 667*, Am. Cyanamid Co.

Notes: Three analyses were made on Aralac which had been previously cleaned by extracting first with ether and then with alcohol in order to remove spinning and softening oils. Nitrogen was determined by macro Kjeldahl and micro Dumas methods. The carbon and hydrogen were determined by micro procedures. The oxygen percentage was obtained by difference. An average of three ash analyses gave 3.03%. The ash contained tricalcium phosphate.

The plastic flow and elasticity are greater in the wet state than in the dry. Because of the greater plastic flow when wet, care should be taken that no undue tension is applied to the fiber in processing. The fiber retains its softness and other desir-

able properties only when it is handled properly and alkali damage prevented.

Aralac is quite similar to wool in chemical composition, except that wool has more than five times as much sulfur. The table on page 169 gives the chemical composition for Aralac, Lanital, and wool, and shows that the proportions of the basic elements are very similar.

The formaldehyde content of Aralac manufactured in 1939 and in August 1942 was determined by several analyses, using, with certain modifications, the method of Nitschmann and Hadorn.

*Comparison of the Formaldehyde Content of Aralac Samples**

<i>Aralac</i>	<i>Formaldehyde (%)</i>
1942 sample	1.03
1939 sample	2.04

* Source: "The Processing of Aralac and Other Protein Base Fibers," H. E. Millson, *Calco Technical Bulletin No. 667*, Am. Cyanamid Co.

An odor of formaldehyde can be detected when Aralac is boiled, and this release of formaldehyde has been used to develop a method for the detection of casein fiber alone and in mixtures.

Alkali Damage. All protein fibers including wool and Aralac soften, gelatinize, and are changed both physically and chemically when boiled or treated at high temperatures in the presence of strong alkalis. The damaged fibers, after drying, are hard and brittle, having lost their natural softness and resilience. These hardened fibers, although spongy, can be powdered by rubbing them between the fingers. Experiments have shown that the damage is permanent and the fibers cannot be fully restored to their previous form by neutralizing or by treatment with softening agents. This is another point of resemblance between casein fiber and wool; wool also becomes harsh and brittle when subjected to excessive alkaline treatments at high temperatures.



Courtesy Aralac, Inc.

FIG. 38. In this apparatus, resembling a huge washing machine, chemicals are recovered for re-use. At this stage, the "tow" is nearly ready for cutting into small lengths.

Boiling. There have been many references in the literature to the danger of a breakdown in the structure of the protein base fibers when boiled even for a short time. This lack of resistance to boiling was a serious drawback because it prevented the use of many dyes with desirable fastness properties. Recently, the resistance of Aralac to most treatments has been increased considerably. However, it is advisable to dye the casein fibers at 180° to 200° F. (82° to 93° C.), whenever possible, and avoid protracted boiling or handling.

Aralac may be dyed for 2 or 3 hours at the boil with acid, without causing any appreciable damage. However, prolonged boiling in strong acid solutions has an adverse effect on the casein fibers. Consequently, when subjected to such treatments there may be a loss of tensile strength which results in an impairment of the fibers.

If Aralac *fibers* are neutral or slightly acid, the boiling time during dyeing should be reduced to a minimum, preferably not much longer than 1 hour. Tests made on neutral Aralac to determine the effect of boiling showed that boiling for 2 hours in a neutral bath resulted in some loss of tensile strength. Boiling should be avoided when processing Aralac even in weakly alkaline solutions.

Hygroscopic Moisture Content. An outstanding property of casein fibers is their ability to absorb and hold hygroscopic moisture without feeling damp or clammy. In this respect, the casein fibers are nearer to wool than those produced from cellulose.

Analyses of the moisture content and regain of Aralac, Lanital, and wool gave the following results:

*Moisture Content and Regain of Aralac, Lanital, and Wool**

	Aralac %	Lanital %	Wool %
Hygroscopic moisture content ...	6.64	8.01	10.90
Regain †	13.58	18.05	12.23

* Source: "The Processing of Aralac and Other Protein Base Fibers," H. E. Millson, *Calco Technical Bulletin No. 667*, Am. Cyanamid Co.

† Percentage regain based on dry weight; temperature 70° F. at 65% relative humidity.

Dry Cleaning. Aralac fibers appear to be quite resistant to solvents ordinarily used for dry cleaning. Colors were generally fast to these agents but some showed "bleeding" which colored the solution. The fastness of dyes will vary if cleaners use a water-solvent soap emulsion for scouring to remove dirt and stains. Acid and milling colors may lose considerable color body if treated in this way. Garments made of fabrics containing Aralac should be cleaned with solvents only and soap emulsions should be avoided unless the fastness of the colors is determined before the treatment.

Resin Treatments. It is expected that the use of resins will improve the wearing qualities and increase the tensile strength of fabrics containing Aralac. Resin treatments may make possible the use of 100% Aralac constructions. Melamine resins show special promise because they are readily absorbed by Aralac and have given excellent results in laboratory experiments. Aralac blends show increased crease resistance when urea-formaldehyde resins are used. There are still some problems that must be solved before practical methods for the application of resins to Aralac and multi-fiber blends can be worked out.

Sensitivity to Sunlight. Wool fibers that have been exposed to light generally dye differently from unexposed wool. Edge streaks on pieces and blotches on skeins are often caused by sun or light bleach. Tests on Aralac show that this fiber is affected by light to about the same extent as wool. Pieces of 100% Aralac cloth were exposed to light and then dyed. The light-bleached areas were dyed heavier or lighter than the unexposed portions, depending upon the dye used.

Detection of Aralac in Mixtures by Burning. One of the easiest ways to detect the presence of Aralac in rayon or cotton mixture is to burn a sample. When burned, Aralac gives off an odor similar to that of burning wool or hair, whereas rayon and cotton have an odor like that of burning cotton string. Since Aralac and wool give odors hardly distinguishable from each other, the burning test can be used only to distinguish Aralac

from nylon, Vinyon, acetate, rayon, or cellulosic fibers. Aside from the difference in odor, nylon and acetate rayon appear to melt and fuse, leaving a hard brown or black residue which is resistant to crushing with the finger nails. Aralac burns readily and leaves charred ends that can be powdered easily between the fingers.

Affinity for Dyes. An outstanding feature of Aralac is its affinity for dyes of all kinds. This is especially pronounced when dyeings are run at low temperatures. The affinity of casein fibers for dyes has been given careful study and the conclusion is that the rate and apparent affinity of Aralac for dyes is dependent upon the acidity or alkalinity of the fiber. If the acid content of Aralac fiber (generally pH 3.8 to 3.9) is neutralized before dyeing by scouring with strong alkalies at low temperatures or boiling for 30 minutes in a pH 7 buffer, its affinity for dyes is greatly reduced, and its power to absorb some dyes is less than that of Australian wool.

If Aralac is strongly acid, the fibers have considerable affinity for dyes of all kinds, but the fixation and fastness vary with the class of dye. Individual dyes also vary in their fastness properties with the result that a dye with good fastness on wool may be poor on Aralac. In general, all wool dyes are less fast on Aralac than on wool. Apparently, the chemical bond between the molecule of wool dye and the Aralac fiber is not so strong as it is when combined with wool. In contrast to wool colors, many vat dyes applied to Aralac have excellent fastness properties.

Improvement in Basic Properties. While a great deal has been accomplished in the development of casein fibers, much work remains to be done. Acetylation (addition of the acetyl group, $\text{CH}_3\text{CO}-$) has provided a method for making such fibers resistant to boiling aqueous solution. Improvement in all of their basic properties within limits of compatibility is desired. These properties are, to a considerable extent, interdependent. It is generally agreed, however, that the most urgent need is for

higher wet and dry strengths. Some of the factors under investigation which have an important bearing on the strength of casein fibers are (1) the pH and viscosity of the spinning solution, (2) the composition of the precipitating bath, (3) the effects of draw-off and godet stretch, and (4) progressive stretching during the hardening process.

So far, it has not been possible to produce a textile fiber from casein showing any orientation detectable by x-ray diffraction patterns. The Eastern Regional Research Laboratory of the United States Department of Agriculture has found that large extruded filaments of casein and other proteins can be converted by moisture, heat or a variety of chemical agents, and mechanical treatment to an oriented structure with chains extended along the fiber axis characteristic of silk and stretched wool. Further investigations are now being carried out by the same laboratory with a view to producing an oriented textile fiber from casein.

APPLICATIONS

Up to the present, Aralac has been used almost entirely in blends. It has been successfully blended with wool, cotton, viscose and acetate staple rayons, and nylon staple; a variety of effects can be obtained in this way. Two and three color combinations can be produced or certain fibers can be dyed while others remain white. Aralac imparts certain wool-like characteristics to fabrics containing rayon or cotton.

A wide range of cloths have been made from Aralac. These include soft wool type coatings, harder finished worsted, and coverts, flannels, gabardines, and serges, as well as challis types and cloths that resemble linen. The Aralac content in the finished cloth may be made to range from 20 to 50%. In 1942, most Aralac blends had a maximum of 20%. This percentage has been gradually increased paralleling improvements in the strength of the fiber. Typical blends contain about 30% Aralac.

Blended with other fibers, Aralac is used to make half hose and anklets, sweaters, and blankets. It is blended with fur and wool for use in felt hats. The largest use of Aralac in the textile

TABLE 9.1. PROPERTIES OF ARALAC*

Tensile strength—dry	Approximately 75% that of wool
Tensile strength—wet	Approximately 30% that of wool
Specific gravity	1.29
Moisture regain	13% at 70° F. and 65% relative humidity
Total water absorbency	About the same as wool
Resistance to heat	Extreme temperatures cause harshness and brittleness, and cause a loss in tensile strength
Effect of acids	Unaffected by weak acids; decomposed by strong acids
Effect of alkalies	Weak alkalies at low temperatures have little effect. Weak alkalies at high temperatures weaken the fiber. Strong alkalies cause softening, gelatinization, and decomposition.
Solubility in organic solvents ..	Insoluble
Affinity for dyes	Has an affinity for acid, chrome, direct and other classes of dyes employed on wool.
Resistance to mold, mildew, and moths	Attacked—similar to wool
Elongation	About the same as wool at standard atmosphere
Clarity	Opaque
Burning rate	Similar to wool
Types and sizes	Staple lengths from 1½ in. to 6 in. (by ½ in. graduations)

Diameter:

- 15 micron, corresponding to rabbit fur
- 20 micron, corresponding to 70's grade wool
- 25 micron, corresponding to 60's grade wool
- 30 micron, corresponding to 50's grade wool

* As reported by Aralac, Inc., a division of National Dairy Products Corp.

field has been in dress fabrics, but it is also used in such articles as coats, men's suits and underwear, neckties, and scarfs.



Courtesy Aralac, Inc.

FIG. 39. From the revolving drum at the top, cut and finished Aralac fiber drops down, ready to be baled and shipped to textile mills and other users.

Aralac is used without blending as filling for cushions, pillows, etc., and in interlinings for coats. It is used in a 100% form as "Wavecrepe," which serves to protect the hair from excess

heat during permanent waving. Dyed Aralac has even been substituted for hair itself in the creation of modish coiffures.

While it is believed that combinations with other fibers offer the greatest field for the use of Aralac, the relatively low wet strength of the present fiber generally makes it unsuitable for 100% textile fabric. Treatments with resin and other types of permanent finishes may overcome this weakness in the future and make it possible to introduce pure Aralac fabrics for general use. Changes in the methods of manufacture and chemical structure of the fiber will, without doubt, bring improvements in the wet strength, dyeing properties, resistance to alkalies, high temperatures, and softness of the finished fibers.

TABLE 9.2. APPLICATIONS OF ARALAC

In Blends

Dress fabrics

Suitings

Coatings

Sportswear

Men's and women's hats

Children's clothing

Snow suits

Ankle socks

Housecoats and robes

Men's ties

Sweaters

Scarfs

Unblended

Quilted garments

Comforters

Garment interlinings

"Wavecrepe"

PRODUCTION AND PRICE DATA

Production of Aralac in 1944 was approximately 8 million lbs. Although the price of casein has fluctuated from 15 to 30¢ a pound in recent years, the price of Aralac has been maintained at 64¢ a lb., which is higher than that of rayon or cotton but lower than that of wool.

About 1 lb. of casein is required to produce a pound of fiber. The source of casein is skimmed milk, which yields about 3% of its weight in this material. Annual production of whole milk in this country is around 120 billion lbs. The separation of cream or butterfat from whole milk for creamery butter and table cream requires about half of all the whole milk produced, leaving from 50 to 55 billion lbs. of skimmed milk, most of which never leaves the farm (since the farmers do most of the separating themselves) and is used primarily for animal feed. This would be sufficient to make about 1.5 billion lbs. of fiber annually.

CHEMISTRY

Casein is a globular protein having a molecular weight around 33,600 as determined by Burk and Greenberg.¹ The chemistry of casein and the nature of its molecular structure are not as yet completely known. The casein molecule itself is a complex system of conjugated amino acids and is classified as a phosphoprotein.

When the casein material is extruded in the filament form, certain changes in its composition occur as it passes through the spinning, precipitating, and hardening baths. These changes depend largely on the chemical composition of the baths and also on other factors such as temperature, pH, time, etc. Thus, about 0.5% aluminum may be taken up from the spinning bath which shows up in an increase in the ash content of the fiber (see table). There is little loss of organic phosphorus in the process. Any loss of organic sulfur from the casein filament in the precipitating bath is offset by the sulfate-sulfur picked up. Formaldehyde is taken up to the extent of about 2% by the casein filament during the hardening process. The following table shows typical changes which casein undergoes when it is converted into the fiber:

¹ *J. Biol. Chem.* **87**, 197 (1930).

Composition of Casein and Casein Fiber,†*

	Casein %‡	Casein Fiber %‡
Carbon	49.13	51.00
Hydrogen	7.18	7.68
Nitrogen	14.80	14.02
Ash	1.88	2.10
Phosphorus	0.86	0.74
Sulfur	0.79	1.14
Aluminum	Trace	0.50
Formaldehyde	None	2.03

* Source: "Textile Fiber from Casein," R. F. Peterson et al, *Industrial and Engineering Chemistry*, Vol. 37, May 1945, p. 492.

† This analysis is representative of the commercial product, a low-ash casein precipitated with hydrochloric acid.

‡ Moisture-free basis.

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Courtesy The Drackett Company

FIG. 40. H. R. Drackett inspecting a batch of soybean fiber as it emerges from spinnerets.

CHAPTER X

Soybean Protein Fiber

SUMMARY

Soybean fiber, the first protein fiber ever made directly from the vegetable world rather than from the animal, has been undergoing development for a number of years. Generally, it is similar to casein fiber in its properties and potential uses.

Soybean protein fiber is somewhat comparable with wool in its resiliency, heat-insulating characteristics, and affinity for dyes. However, its dry strength is considerably below that of wool, and its wet strength so inferior as to constitute a distinct handicap.

The new protein fiber should sell at around the same price level as casein fiber and find its principal market in blends with cotton, wool, and rayon.

HISTORY AND DEVELOPMENT

Soybean fiber was first developed by the Ford Motor Company about 1939. Pilot plant production was started in early 1941, and by the end of 1942 output was reported to have reached a level of 1000 lbs. a day.

In December 1943, H. R. Drackett, president of The Drackett Company, announced that his company had acquired from the Ford Motor Company their soybean process and pilot plant equipment. Robert Boyer, who was chief research chemist of the Ford Motor Company, joined The Drackett Company as its research director.

The Drackett Company had pioneered in soybean development work and originally supplied the Ford Motor Company with the soybean protein "alysol."

Research on soybean fibers has been carried on at the Northern Regional Research Laboratory of the United States Department of Agriculture and by a number of companies and organizations.

MANUFACTURE

The oil is extracted from the soybean through the use of a solvent, leaving a residue of soybean meal. The protein is removed from this meal by treating it with a weak alkaline solution, such as 0.1% sodium sulfite. The resulting solution is then clarified, by either filtering or centrifuging. The protein in the curd is precipitated by an acid, and then the resulting curd is washed and dried.

The precipitation must be carried out at just the right temperature and pH in order to get a curd that can be handled satisfactorily during the subsequent washing and drying.

Next the protein is dissolved to produce a viscous solution of about the same consistency as molasses. This solution must be controlled carefully and must have a high solids content (which is difficult because proteins in high concentrations tend to form a gel). Yet, with careful control, it is possible to produce solutions with as much as 20% protein. The solution must then be aged until the required viscosity and stringiness are reached.

The aged solution is forced through spinnerets into an acid precipitating bath, and the resulting filaments are collected from this bath on bobbins or reels. These filaments must be stretched as they are collected. This is done by pulling them through the acid bath and over two glass pulleys, one of which revolves faster than the other to exert the desired stretching effect.

The fiber is then set by long immersion in a formaldehyde bath and is dried under controlled humidity and temperature, after which it is cut into desired lengths. It is then ready for shipment.

PROPERTIES

In appearance, soybean fiber is a loose, fluffy mass with a resemblance to scoured wool. Its color varies from light tan to white. It has a medium luster between that of wool and that of mohair. It has a rather warm, soft feel, and good resiliency.

Microscopic Characteristics.¹ In cross section, the fibers are nearly circular and highly uniform. The fineness measurements of two samples of soybean fiber for 1944 and 1939 were as follows:

<i>Types</i>	1944	1939
No. of fibers	400	200
10-20 microns	12 $\frac{0}{10}$	1 $\frac{0}{10}$
20-30 microns	84.25 $\frac{0}{10}$	97 $\frac{0}{10}$
30-40 microns	3.5 $\frac{0}{10}$	2 $\frac{0}{10}$
Over 40 microns	0.25 $\frac{0}{10}$	.....
Average microns	23.18	26.81
Standard deviation	3.63	2.04
Coefficient of variation	15.65	7.61

It is noteworthy that the coefficient of variation which reflects the uniformity of the fibers was twice as high in the 1944 product approaching the variation in wool fibers, which ranges from 19 to 25%. The staple length is approximately 2 inches.

Tensile Strength.¹ The tensile strength test of soybean fiber, compared with wool of the same grade, gave the following results:

	<i>Soybean staple (1944)</i>	<i>Wool top 62s</i>
Tensile strength, dry, lbs./sq.in.	11,450	21,000
Tensile strength, wet, lbs./sq.in.	4,240	17,700
Strength loss from dry, %	63	15.8

Note: Bundle test, 65% relative humidity, 70° F.

¹ "The Soybean Fiber as Seen by a Wool Man," Werner von Bergen, *Rayon Textile Monthly*, May 1944.

The tensile strength of soybean fiber in the dry state was approximately 55% that of wool and in the wet state only 24% that of wool.

Moisture Regain. When measured under standard conditions of 65% relative humidity and 70° F., the fiber came to equilibrium from the wet state at 16.1% regain and from the dry state at 12.9% regain, showing a similar hysteresis as wool.

Heat Resistance. In the conditioning oven where the soybean fiber was exposed to 220° F. a considerable yellowing took place, indicating that the fiber could not withstand a high temperature. Casein fibers showed the same yellowing under similar treatment.

Chemical Properties. Soybean fiber is acid having a pH of 3.0. The test for formaldehyde with carbazole was positive.

Effect of Caustic Soda. In a 5% boiling caustic soda solution, approximately 11 minutes were required to dissolve the 1944 sample of soybean fiber, compared with 4 minutes for the 1939 sample. This difference also is reflected in the change of the swelling characteristic with N/10 caustic soda. The following increases in fiber diameter were found:

	1944 Sample	1939 Sample *
	<i>Microns</i>	
Glycerine	23.2	26.6
Water	27.5	32.8
N/10 caustic soda	31.3	43.6
	<i>Per cent</i>	
<i>Swelling</i>		
Water	18.7	23
N/10 caustic soda	35.1	63.5

* Source: "The Soybean Fiber as Seen by a Wool Man," Werner von Bergen, *Rayon Textile Monthly*, May 1944.

The above results (for 1944) were about the same as for casein fiber.

Carbonizing and Dyeing. The soybean fiber resists carbonizing with 4% sulfuric acid, but turns yellow. In the acid condition, it is quite harsh and brittle, and by neutralization, the original softness is only partially restored. The fiber shows a high affinity for acid and chrome colors, but when dyed at pH's below 3, the fiber becomes very harsh and brittle. At the pH of 7, the fiber dyes a very deep red with Benzopurpurin. This shade is considerably deeper than that obtained on casein fiber at the same pH.

TABLE 10.1. PROPERTIES OF SOYBEAN PROTEIN FIBER*

Tenacity, dry	0.70 gm./denier
Tenacity, wet	0.35 gm./denier
Moisture regain	10 to 12%
Specific gravity	1.31
pH	3 to 3.5
Resiliency	Good
Insulating ability	Equal to wool
Felting ability	Fair
Dyes used	Wool-type: fast acid and chrome
Effect of solvents (dry cleaning) ..	None
Color	Light buff
Staple fiber length	1/4 in. to 6 in.
Crimps per inch	0 to 12
Denier range	3 to 12

* Source: The Drackett Co. (March 1945).

APPLICATIONS

Soybean fiber can be blended with other fibers, or it can be woven or spun unblended.

According to The Drackett Company, soybean fiber has been made experimentally into blankets, hosiery, rugs, carpets, upholstery, underwear, hats, suitings, and other products.

ECONOMIC ASPECTS

It is anticipated that soybean fiber will sell at about 65¢ per pound, about the same as that of casein fiber. This would be

much lower than that of wool, although higher than cotton and rayon.

Potentially, the basic material for making the fiber, like that for casein, is abundant and cheap. Production of soybeans has shown rapid growth since 1930, when it was of negligible proportions. It is now more than 200 million bushels annually.

Five pounds of soybeans are required for 1 lb. of protein, which in turn will make 1 lb. of fiber.

The 1941 crop would have yielded about 250 million lbs. of fiber, if it had all been processed for that purpose.

STATUS OF DEVELOPMENT OF SOYBEAN PROTEIN FIBER IN 1945

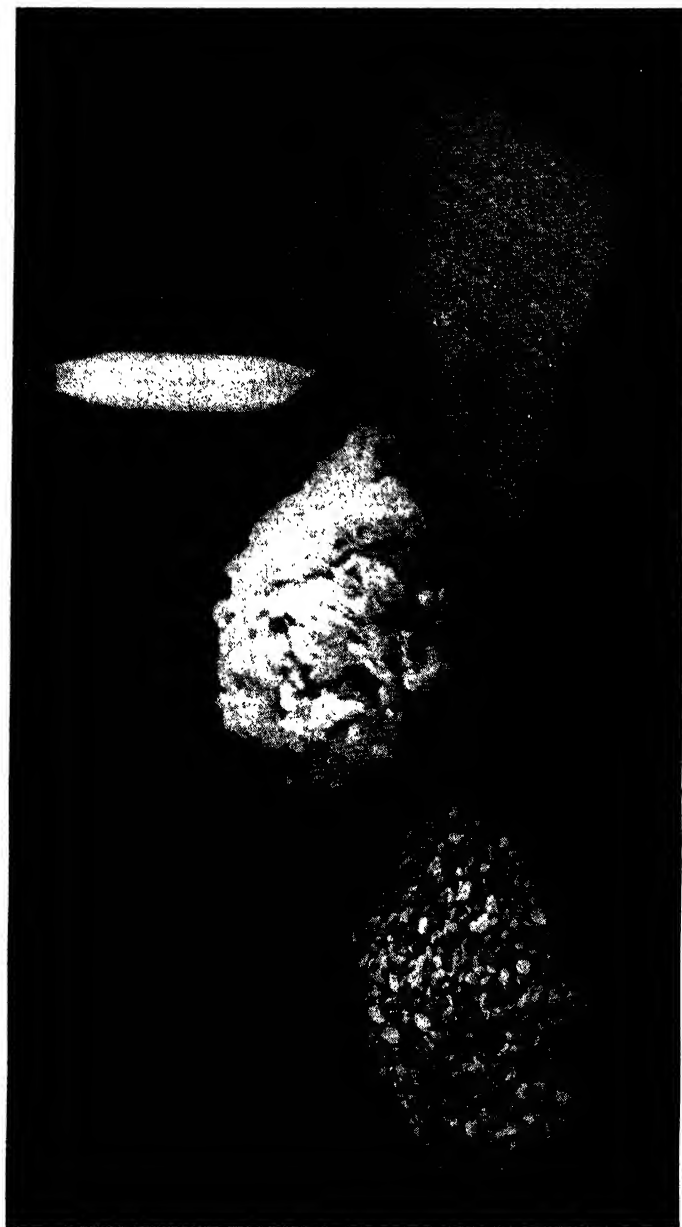
Regarding soybean protein fiber, The Drackett Company reports:

The product is still in the development stage and will probably not undergo any considerable change until shortly after the first of the year when we expect to move into a new plant which is built and now being equipped. We have reason to expect that the new plant will produce better quality fiber from the standpoint of filament strength and color and it will have much greater capacity than the small pilot plant in which we have been operating.

We are now opening up relationships with various companies in the textile fields for purposes of experimental spinning, weaving and knitting along with the supplemental textile operations such as dyeing and finishing. This work is progressing nicely so that by the time our new plant is in operation we should be ready to go ahead on a limited scale of commercial operation.

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Courtesy Imperial Chemical Industries, Ltd.

FIG. 41. From peanuts to Ardil fiber, then to yarn and to material.

CHAPTER XI

Other Protein Fibers

SUMMARY

Just as fibers can be made from a wide variety of synthetic substances, so can they be made from a number of proteins. Fibers have been formed from the proteins of milk, soybeans, peanuts, corn, fish, chicken feathers and eggs. All of these materials are potentially abundant and cheap, and the quantities going to waste throughout the world, if made into fibers, would probably be sufficient to keep every man, woman, and child well clothed.

Among the protein fibers about to emerge from the development stage are those made from peanuts and corn.

In Great Britain, attention has been turned to peanuts because of the vast quantities grown throughout the British Empire. Peanut fiber has been developed to a stage of commercial usefulness by Imperial Chemical Industries, Limited.

In the United States, considerable research on corn protein fiber is being carried out by the United States Department of Agriculture, as well as by Corn Products Refining Company and other commercial organizations.

In general, the man-made protein fibers can be produced much more cheaply than wool, a natural protein fiber. The new protein fibers have many of the general properties of wool. Some of them can be made even stronger than wool in the dry state. But all of them have in common a low wet strength, which weakness must be overcome if they are to gain the widespread commercial acceptance that their potential abundance and economy of use would warrant.

In the foreseeable future, the new protein fibers will probably find their biggest uses in blends with cotton, rayon and wool, rather than as self-sufficient fibers. They will be more complementary to the established fibers than competitive with them.

MANY FIBERS POSSIBLE FROM PROTEINS

The proteins produced in nature are structurally of two kinds: those of protective tissues, designated as keratins and represented by such materials as feathers, horns, hoofs, and hair; and those of the soft tissues of both animals and plants.

The keratins have been found by physical measurements to have a fibrous molecular structure; their long-chain molecules are extended linearly and locked in this position. These materials are resistant to the solvent action of acids and alkalies, soften to a limited extent when heated, absorb water and swell readily without disintegration. They are somewhat resistant to the action of microorganisms and enzymes.

The proteins of soft tissues, on the other hand, are shown by physical measurements to be roughly globular or spherical in molecular structure. They dissolve readily in water solutions of acids and alkalies and soften with heat, especially in the presence of water. They absorb water and swell to an extent approaching dissolution. They are readily attacked and acted upon by microorganisms and enzymes.

Since the keratin proteins are the more stable of the two kinds, it might be assumed that they would be more widely used industrially. The contrary, however, is true, because the softer globular proteins are more readily soluble and are available in purer form and in greater supply. Thus casein, the curd of sour milk, is the most widely used, while the proteins of soybeans, peanuts, corn, and other food plants are undergoing intensive development.

At the Western Regional Research Laboratory of the United States Department of Agriculture, investigations of the proteins derived from feathers, wheat, and eggs have been under way in

an effort to determine their structure and the possibilities of modifying them for practical purposes. The research program has included the preparation of fibers from fibrous protein, and also from globular proteins converted to fibrous form by suitable treatment. Chicken feathers, representing keratin protein, and egg albumin, representing globular, have been used extensively in these studies.

The Laboratory reports that results from egg albumin and chicken feathers have been encouraging, but wheat protein must be used in a mixture with egg albumin, or some other similar material, in order to give fibers.

Research work of the Laboratory has shown that a detergent, such as sodium alkyl benzenesulfonate, in water solution is a solvent for both globular protein and a mixture of keratin and a reducing agent. The detergent is more than a solvent, since it releases the forces holding the globular molecule so that it can assume the linear or fibrous form. Moreover, the detergent reacts with the side chains in fibrous or linear molecules, thus holding the chains extended until the solution can be extruded through a spinneret.

The spun fiber of both the originally fibrous and converted fibrous proteins can be treated with either acetone or acetone and salt solution. This breaks the chemical combination between the protein and detergent and extracts the detergent, leaving the protein with chains extended in the direction of the fiber axis. The fibers are stretched, preferably in steam, to the extent of 300 to 400% or more. X-ray diffraction patterns show distinct and definite fiber orientation and the tensile strength, dry, is greater than that of wool and approaches that of silk.

The tensile strength when wet, however, is not high. The low wet tensile strengths of all the manufactured protein fibers is a common weakness that must be overcome if these fibers are to have more than very restricted application. This problem is under investigation at present and methods are being sought to produce fibers with improved wet strength.

Egg albumin fibers were equilibrated 24 hours at 70° F (21° C.) and 65% relative humidity. Measurements made on the Scott inclined-plane tester show that, with the increase in orientation as a result of stretching, there is a corresponding increase in tensile strength.

<i>Elongation in Steam *</i> (%)	<i>Average Tensile Strength</i> (lbs./sq. in.)
100	18,000
200	25,000
300	28,000
400	38,000

* Source: "Artificial Fibers from Corpuscular and Fibrous Proteins," Harold P. Lundgren et al, *Industrial and Engineering Chemistry*, Vol. 36, April 1944, p. 370.

Fibers have been prepared from chicken-feather keratin and egg albumin possessing tensile strengths of more than 70,000 lbs. per sq. in. These values compare favorably with those of natural fibers:

<i>Fiber *</i>	<i>Breaking strength</i> (thousands of lbs./sq. in.)
Flax	Up to 156
Ramie	129-135
Nylon	72-100
Cotton	40-111
Viscose rayon	31-88
Acetate rayon	23-110
Silk	46-74
Egg albumin (tech.)	20-70
Chicken-feather keratin	Up to 80
Wool	17-25
Casein (commercial)	Up to 10
Soybean (commercial)	Up to 10

* Source: "Artificial Fibers from Corpuscular and Fibrous Proteins," Harold P. Lundgren et al, *Industrial and Engineering Chemistry*, Vol 36, April 1944, p. 370.

Along with the increase in orientation and tensile strength, there is a corresponding increase in water resistance. Even though

they have not been fixed, the fibers with a high degree of molecular orientation show moisture retention comparable to that of wool, as shown in the following table:

Fiber *	Per cent relative humidity				
	15	30	50	70	90
	Per cent water on dry basis				
Oriented egg white	6.0	7.3	11.0	13.5	25
Wool	6.3	9.0	12.2	17.0	22.9
Raw silk	5.0	7.1	9.0	13.3	19.0
Catgut	6.2	8.6	12.0	17.3	21.7
Viscose rayon	5.6	6.7	9.4	12.9	16.8

* Source: "Artificial Fibers from Corpuscular and Fibrous Proteins," Harold P. Lundgren et al, *Industrial and Engineering Chemistry*, Vol. 36, April 1944, p. 370.

As expected, the range of elastic deformation of the fibers decreases as the degree of orientation increases.

Potential Supplies of Some Fiber-Forming Proteins in the United States (Available Annual Production)

Skim milk—50 to 55 billion lbs. sufficient to make 1.5 billion lbs. of casein.

Corn—100 million bushels sufficient to make 250 million lbs. of zein.

Chicken feathers—170,000,000 lbs. available.

Egg white, inedible—26,000,000 lbs. go to waste.

PEANUT PROTEIN FIBER

History and Development. Just prior to the outbreak of the war in Europe, there was developed in England a wool-like fiber made from peanut protein. It was known as "Ardil," the registered trade name of Imperial Chemical Industries, which undertook experimental production at its Ardeer factory. The development was carried through all the processing stages up

to and including the weaving of cloth. The product appeared very promising and ready for commercial production, but the war intervened. Peanuts normally imported into England from India and West Africa were needed for food.

Development work on peanut fiber has been resumed in England and some information has been made available on Ardil.

Similar work was undertaken by the United States Department of Agriculture at the Southern Regional Research Laboratory. They report, "In some exploratory work on a laboratory scale, we have produced from peanut protein continuous filament fibers which are believed to have interesting and useful properties. To date no technical information has been released covering the process used or the properties of the fibers obtained. The work is still in a preliminary stage."

The globulins in peanut protein are known as arachin and conarachin. Of these, conarachin is much more soluble than arachin. Oil-free peanut meal contains about 24% arachin and about 9% conarachin.

Manufacture of Ardil. Most of the peanut proteins dissolve readily in alkali, but spinnable solutions cannot be obtained simply by extracting the meal with the alkali. To get satisfactory spinning properties, it is necessary to prepare the alkaline solution from the precipitated protein under special conditions. Generally, a solution of 20 to 30% concentration of protein is dissolved in dilute alkali so that the initial pH of the solution is at least 12.5. There is a certain "maturing" period before the solution reaches the spinnable viscosity, which is usually between 50 and 300 poises.

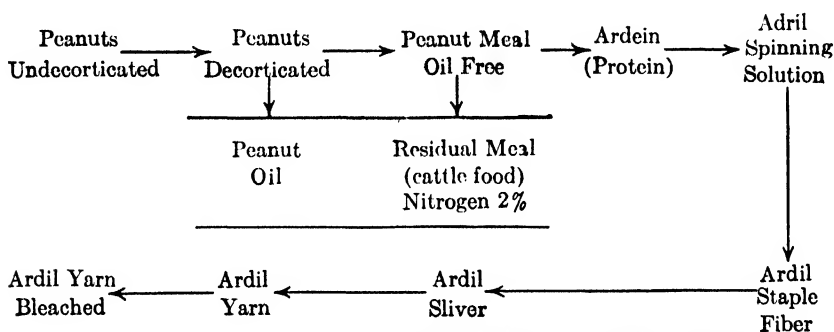
The protein solutions are extruded or spun in a manner similar to that employed in the manufacture of viscose rayon. The solution is extruded at a constant rate through a spinneret into a coagulating bath containing about 15% sodium sulfate and 1% sulfuric acid, the temperature range being 25° to 40° C. (77° to 104° F.). The issuing filaments are collected at a speed greater than the speed of extrusion, thus stretching the fibers.

The filaments are kept under tension for a period to prevent shrinkage.

If the fibers were dried at this stage without any further treatment except washing to remove acid and salts, the resulting matt, white, brittle fibers would disintegrate into powder upon handling.

A satisfactory hardening treatment was found to be the use of an aqueous solution of a soluble halide of an alkali; for example, sodium chloride, or ammonium or magnesium halides

Ardil Manufacture:



Courtesy United States Testing Company, Inc.

FIG. 42.

containing dilute hydrochloric acid, and dilute formaldehyde. To prevent swelling of the fibers and their tendency to stick together, a saturated solution of sodium chloride or other salt is used. The acid concentration need not exceed 2%; thus hydrolysis of the protein is avoided. The reaction is carried out at a temperature between 35° and 50° C. (95° and 122° F.). The fibers are then washed to remove salts and acid. For satisfactory dyeing, the pH of the solution is adjusted to about 8.

Ardil can be used in a 100% form or blended with other fibers, such as wool, rayon or cotton. It has been processed successfully on the worsted, the woolen, and the cotton systems.

Properties of Ardil. Ardil is a cream colored fiber with a soft wool-like "hand" and a moderate luster. Crimp is developed

in the fiber by shrinkage during its manufacture. If the fiber is wetted, stretched and then released, a crimp similar to that in merino wool develops and remains after drying. The fiber is resilient and is said to be more crease resistant than cellulosic fibers. The fiber is approximately circular in cross section and can be made in any desired length.

Tensile Strength and Elongation. The tensile strength of Ardil is 10 kg. per sq. millimeter or 14,000 lbs. per sq. in. Its elongation at break is from 50 to 100%.

Birefringence. Compared with viscose rayon, polyethylene and nylon, Ardil has a negligibly low birefringence. This is in accord with the x-ray evidence which gives only meager signs of orientation in casein, soybean, or peanut fibers. It is possible to produce peanut protein fibers which have a coefficient of birefringence which is just measurable. These fibers are invariably stronger than Ardil, but are generally deficient in other properties, such as crimp and dimensional stability.

Shrinkage. Ardil-wool blends shrink to the same extent as wool. Ardil itself does not shrink, but when wet and plastic it is apparently carried along with the wool fibers.

Water Absorption. The absorptive capacity of Ardil for water is somewhat higher than that of wool. At the same relative humidities, Ardil absorbs as much moisture at 95° F. as wool does at 77° F. Since, at constant relative humidity, the water absorption by wool decreases as the temperature rises, wool at 95° F. absorbs less water than at 77° F., and consequently less than Ardil at the same temperature.

Ardil, wool, and cotton all show hysteresis effects with water; that is, the amount of absorbed water in equilibrium with any given aqueous atmosphere, if measured within a reasonable period, is less if this amount has been attained by evaporation from the fiber than if it is attained by absorption into the fiber. The hysteresis for Ardil is about the same as that of wool, but less than that of cotton. It appears that at 50% relative humidity the differences between the amounts of water present during absorption and desorption are 10% for Ardil and wool,

and 20% for cotton. While it is doubtful whether the useful qualities of a fabric depend on the thermal values of water absorption, a low hysteresis should, on the whole, be advantageous.

The indicated heats of complete wetting of Ardil and wool are as follows:

	<i>Calories/gram</i>
Dry Ardil	19
Ardil (containing 10% water)	8
Dry wool	24
Wool (containing 12% water)	7

Felting. Ardil does not felt in the same manner as wool and fur, in which cases felting is in a large measure the result of the scales on the fibers. The protein fibers show another type of felting, based on their properties of "welding" or "sticking" when held in contact under heat and pressure. This property is useful in hat making.

Wearing Qualities. Wear tests on a series of fabrics containing Ardil were made on an abrasion apparatus developed by the Shirley Institute in England. In these tests, known as the "boss" tests, circular samples of fabrics, $\frac{5}{8}$ in. in diameter, were held against a $\frac{1}{2}$ in. diameter steel ball in a grip which was rotated against a reciprocating belt of unsized grey cotton canvas. The number of rubs which each fabric sustained, before there was a complete hole, was noted. The mean results of tests on five samples of each fabric are as shown in Table 11.1.

Ardil when used alone has poor resistance to abrasion, but it does not reduce the wear of other fibers as much as might be expected. Actually, in one case, 50/50 Ardil/viscose rayon, the Ardil raises the wear value. A possible explanation is that its smooth fibers have a lubricating effect and prevent the striated viscose rayon fibers, which have a dentated cross section, from wearing each other away.

In actual wear tests on more than 80 suits, coats, dresses, etc., made from mixtures of Ardil-wool and Ardil-viscose rayon, the

results indicate that the wearing qualities of these blended fabrics are approximately the same as 100% wool.

TABLE 11.1*

Type of fabric	Weight of fabric (oz./sq.yd.)	Average no. of rubs required	
		Dry canvas	Wet canvas
1st Series			
100% Viscose rayon serge	8.8	400	50
50/50 Ardil/viscose rayon serge	8.9	450	110
100% Ardil serge	8.1	80	30
2nd Series			
100% Wool tweed	11.0	1,500	860
60/40 Ardil/wool tweed	8.1	210	140
100% Ardil tweed	8.3	30	20
3rd Series			
100% Wool Army overcoating	19.4	2,800	2,300
20/80 Ardil/wool Army overcoating	20.0	2,600	2,400
50/50 Ardil/wool ladies' overcoating	10.2	550	280
25/75 Ardil/wool vicuna overcoating	16.4	1,900	1,500
4th Series			
25/75 Ardil/wool worsted	11.8	1,150	850
50/50 Ardil/wool worsted	12.0	1,050	800

* Source: "Vegetable Proteins and Synthetic Fibres," David Traill, Imperial Chemical Industries Explosives, Ltd., Great Britain, November 1944.

Thermal Insulation. Tests for thermal insulation were carried out on a similar series of fabrics. The results showed that an all-Ardil fabric and an Ardil-wool fabric give the same thermal insulation as an all-wool fabric of equal thickness and structure.

Dyeing Properties. By virtue of its chemical structure, Ardil has an affinity for dyestuffs normally used in dyeing other protein fibers. Since its physical structure is not identical with that of the natural protein fibers such as silk and wool, its dyeing properties are different from these fibers, although intermediate between the two.

Its behavior toward acid dyestuffs closely resembles, but is not identical with, that of chlorinated wool. Like the latter, it has an increased rate of dyestuff uptake, and the dyeings obtained have a reduced wet fastness compared with the same dyestuff

on normal wool. In dyeing Ardil-wool blends, solid shades are obtained readily by the application of level dyeing acid dyestuffs from a boiling dyebath set with Glauber's salt and sulfuric acid.

In dyeing with acid milling dyestuffs, the color originally taken up by the Ardil is transferred to the wool during the dyeing process, and the degree to which this occurs depends on the dyeing time. Consequently, perfect solid colors are not generally obtained, particularly with three color mixtures, although in self-shades the results may often be satisfactory.

Ardil also possesses good affinity for direct cotton dyestuffs, and blended with either viscose rayon or cotton, it may be dyed by suitable selection of dyestuffs.

TABLE 11.2. PROPERTIES OF ARDIL.*

Tensile strength	10 kg./sq. mm. (14,000 lbs./sq. in.)
Elongation at break	50-100%
Water absorption	Somewhat higher than wool
Heats of complete wetting:	<i>Cal./gm.</i>
Ardil (dry)	19
Ardil (10% water)	8
Dyeing properties	Closely resembles that of chlorinated wool
Thermal insulation	Same as wool
Natural appearance	Cream colored crimped fiber with soft luster and wool-like hand

* Source: Imperial Chemical Industries, Ltd.

ZEIN (CORN PROTEIN) FIBER

Zein, the protein of corn, is a prolamine having a molecular weight around 40,000. It is soluble in 80% alcohol and insoluble in water or dilute salt solutions. Zein reacts with bases but not with acids, and for this reason it dissolves in alkaline solutions but not in acids.

Processes for making protein fibers from zein have been patented by L. C. Swallen (Corn Products Refining Company) and F. M. Meigs (E. I. du Pont de Nemours & Co.).

The Swallen process involves the use of organic solvents such as ethyl alcohol in the preparation of the spinning solution. This process also uses 20% or more of plasticizer, and 2 to 5% of formaldehyde in the spinning dispersion, and the solution is extruded through standard spinnerets. The extruded filaments are solidified by evaporation of the solvent (dry-spinning) or by a liquid coagulant (wet-spinning).

Meigs has described a wet-spinning process for a wide variety of proteins, namely, the "globulins, prolamines, and phosphoproteins," and includes zein among the proteins listed.

The investigation carried out by Northern Regional Research Laboratory, Peoria, Ill., has resulted in the development of a new process for making zein fibers by a wet-spinning method. The equipment used in this process is similar to that employed in the manufacture of viscose rayon, and certain protein fibers.

By this process, zein fibers which have good tensile strength and wool-like properties are produced from alkaline dispersions of zein. The spinning dispersions are formulated to produce a high viscosity by the use of denaturing agents, such as alcohol or urea, or by aging the solutions. The filaments are coagulated in an acid bath in which salts may or may not be used. The coagulated filaments are given a mild formaldehyde precure prior to stretching and drying. The extent of the precure, as determined by the concentration of formaldehyde and by the time and temperature of treatment, greatly influences the character of the fibers. Shrinkage and water resistance of the fibers are controlled by acetylation followed by a strong formaldehyde treatment.

Properties. Inasmuch as the process for the production of zein fiber is not yet fully developed, a complete description of its properties cannot be given. However, a preliminary survey of fiber properties is presented to indicate the promising possibilities for the establishment of a commercial fiber from corn protein.

The zein fibers produced by the process developed by Northern Regional Research Laboratory are claimed to have good

wet and dry strengths. Dry strengths of 1.87 grams per denier and wet strengths of 0.75 grams per denier have been obtained.

Zein fibers have high resilience and are very flexible, although no plasticizer is used. Fibers finer than 0.6 denier (7.5μ in diameter) have been produced by applying a high stretch in a heated coagulating bath.

The fibers prepared by the above-mentioned process shrink to their precured length when immersed in hot water. This shrinkage can be reduced greatly by treating the fiber, while held under tension, with strong formaldehyde. Nevertheless, there is some loss in strength from the maximum values, and the fibers from this "post-cure" measure from 1 to 1.25 grams per denier.

In preliminary studies on dyeing zein fibers, it was found that after post curing with strong formaldehyde, the fibers will not withstand the severe acid conditions normally used in dyeing and processing wool. In this respect, zein fibers are similar to casein fibers and, like casein, the dyeing properties, in general, are greatly improved by acetylation. Acetyl contents above 2% are necessary to give satisfactory resistance to acid-dye bath conditions. Acetylation followed by curing with formaldehyde has given a satisfactory control of shrinkage. In some cases, the shrinkage has been lowered to 4% as determined by boiling for 15 minutes in water.

From a study of the acid and alkaline peptization curves of zein, the fibers would be expected to offer considerable resistance to the usual alkaline conditions encountered in the use of soaps and scouring powders. Acetylated and properly cured fibers have shown excellent resistance to boiling in buffered solutions of pH 8 to 9, and, in some cases, have shown no loss in strength upon boiling for 2 hours at this alkalinity. Fiber texture, feel, and appearance were not impaired by this boiling treatment.

Patent Information. U. S. 2,156,929 (May 2, 1939), "Zein Filaments," is assigned to Corn Products Refining Company. This is the same as British Patent 492,655 (September 19, 1938).

Filaments can be produced by extruding a solution of zein through a filament-forming orifice into an aqueous coagulating medium containing formaldehyde; withdrawing the filaments and heating them to evaporate water and induce a reaction between formaldehyde and zein.

The coagulating medium may be either a liquid or a gas, and the formaldehyde may be incorporated in the zein solution, in the coagulating fluid, or in both. A number of modifications are possible.

The zein solutions may be prepared simply by adding the desired amount of formaldehyde or other aldehyde to a solution of zein in aqueous ethyl alcohol or a similar solvent such as methyl alcohol, "carbitol" (diethylene glycol), "cellosolve" (monoethyl ether of ethylene glycol), diacetone alcohol or the like. The zein concentration of the solution may be adjusted to any suitable value for extrusion, depending upon the size and nature of the orifice, the pressure to be employed, and other factors. An amount of aldehyde equivalent to 2% of free formaldehyde, based on the weight of the zein, is usually required to give satisfactory strength and water-resistance to the product. However, larger amounts up to 50% by weight may be used.

Although an unplasticized solution may be satisfactorily used for the extrusion of filaments, it is preferable to add a plasticizer in order to obtain the desired degree of flexibility and resilience in the product. Suitable plasticizers are dibutyl tartrate, monobutyl phthalate, or p-toluene methyl sulfonamide. The amounts of plasticizer up to 20% or more, based on the weight of the zein, will generally be suitable, and for most purposes from 10 to 20% will be found satisfactory.

The zein solutions may be extruded in any type of apparatus, such as that used in rayon manufacture. The solution may be extruded into air, in which case coagulation will result from the evaporation of solvents, or it may be extruded into water or other liquid coagulating medium.

After solidification of the filament and before winding, it is necessary to apply heat in order to obtain satisfactory initial

strength. If a gaseous coagulating medium is employed, heated gas will serve both to evaporate the solvents and to effect a reaction between the zein and aldehyde. If a liquid coagulating medium is used, the filament should pass through a heated chamber prior to winding. Any suitable means may be employed for this purpose, and the heat treatment may be performed simultaneously with other operations such as imparting the desired amount of tension or twist to the filament.

The heating may be effected in a vertical tower through which heated air is passed in an opposite direction to that of the filament. The temperature should not be allowed to go much above 212° F. (100° C.) because of the water content of the material and the possibility of injurious effect of higher temperatures upon proteins. Temperatures of 140° to 194° F. (60° to 90° C.) have been found satisfactory, and a treatment of approximately 5 minutes at such temperatures usually imparts sufficient strength to the material.

The reaction between zein and the aldehyde will continue to completion upon storage at ordinary temperatures. However, at such temperatures the reaction is relatively slow and it is preferable to heat the filament further to give it initial water resistance. For this purpose, the material may be baked at temperatures of 140° to 194° F. (60° to 90° C.) for a period of 8 to 10 hours. This operation may be carried out at any suitable stage of the processing, for example, when the filament is first spooled, but is preferably effected when the material is in a loose form, as in skeins.

A modification comprises the use of solutions of zein in aqueous formaldehyde without organic solvents. It has been found that aqueous formaldehyde exerts a solvent and plastifying effect upon zein. The zein may be kneaded with aqueous formaldehyde to obtain a mass suitable for the production of plastics. Such solutions are usually too viscous for satisfactory extrusion, so that for making filaments a more dilute solution should be used. By employment of suitable apparatus, additional plasticizers may be incorporated into the solution to reduce viscosity and facilitate

extrusion. Solutions of this type may be employed in the same manner as the solutions in aqueous solvents already discussed. The coagulating medium may be either a liquid or a gas, and the procedures previously described will apply here.

A further modification comprises the use of zein solutions without aldehydes. In such cases the solution is extruded into a medium containing the desired concentration of formaldehyde or other aldehyde. For this purpose, solutions of zein in aqueous organic solvents may be employed and plasticizing agents may be added if desired. Such solutions may be extruded into aqueous formaldehyde or a solution of other reactive aldehyde, or they may be extruded into a gaseous medium containing formaldehyde vapor. The same general procedure as to extrusion and heat treatment previously described also applies here.

TABLE 11.3. QUALITIES OF FIBER PREPARED FROM DIFFERENT PROTEINS *

<i>Fiber</i>	<i>Untreated— water content after immersion in water † (22 to 25° C.) (%)</i>	<i>Formaldehyde- hardened— water content after immersion in 2% formaldehyde (22 to 25° C.) (%)</i>	<i>Lysine content (%)</i>	<i>Flexibility of formaldehyde- hardened fibers</i>
Casein	42	25	6.3	Good
Gelatin	93	58	5.9	Good
Zein	28	25	0.0	Brittle
Edestin	34	33	2.3	Brittle
Arachin	31	30	1.7	Brittle
Glutenin	60	51	1.9	Brittle
Soybean protein	45	26	4.9	Good

* Source: "Artificial Bristles from Casein," T. L. McMeekin, Eastern Regional Research Laboratory, *ASTM Bulletin*, December 1943.

† Chloroform was used as a preservative.

It is claimed that zein filaments have satisfactory strength and excellent water resistance after final cure. It is further claimed that filaments of low denier can be made for use in any of the standard types of yarns. Such materials are said to have satisfac-

tory elasticity and resilience, as well as excellent appearance. Alcohol-soluble dyes may be incorporated into the organic solvent solutions or the final products may be dyed. For these reasons zein filaments would be suitable for use in the textile industry.

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Courtesy Celanese Corporation of America
FIG. 44. Rayon yarns are woven into a wide variety of fabrics in various weights.

CHAPTER XII

Improved Rayons

SUMMARY

The reader may wonder why rayon is considered one of the new fibers, since it has been on the market for more than 30 years. The answer is that rayon has undergone such extensive improvements in quality and adaptation to new uses, that it is for all practical purposes a new fiber. Certainly the rayon which is in use today or under development is so much better than the rayon that was first introduced that it is as much a new fiber as nylon or casein fiber. This is particularly true of some of the special types of rayon recently introduced. But first let us consider the great improvements that have taken place in the run-of-the-mill rayon that has won such wide popularity among consumers.

The rayon on the market today is stronger and softer, drapes better, dyes better, and looks better than the rayon of 30, 20, or even 10 years ago. It is more uniform in its quality and cheaper in price than the earlier rayons.

Based on cellulose, the most abundant plant material in nature, rayon can be tailored to meet specific requirements. Its range of properties has been so greatly extended that it is difficult to draw the line between improved rayons and new types. One type can be made as strong as nylon, another as fine and soft as silk, while still another can be given characteristics of cotton or wool—these are just a few of the newer types.

The three basic types of rayon—viscose, acetate, and cuprammonium—have all shared in the general advances made by the industry as a whole. For the convenience of the reader, the chap-

ter includes brief descriptions of the three basic processes for making rayon.

MANUFACTURE OF RAYON

In the manufacture of rayon, three methods are generally used: the viscose process, the cellulose acetate process, and the cuprammonium process. The fourth process, the nitrocellulose process, is no longer used in the United States. The methods of making rayon differ considerably according to the process used. However, the following three steps are basic:

- (1) Cellulose is changed into a liquid form.
- (2) The liquid is drawn out into very fine streams.
- (3) These liquid streams are changed into solid cellulose filaments and combined into continuous yarn, or made into short lengths known as "rayon staple fiber."

Brief descriptions of the three basic processes for making rayon follow.

Viscose Process. The first step in the viscose process is steeping, or mercerization. This is accomplished by soaking the sheets of cellulose in a solution of sodium hydroxide. The cellulose sheets are allowed to soften for a definite length of time and the excess liquid is then squeezed out by a hydraulic ram, leaving a batch of moist sheets of alkali cellulose.

The second step is shredding. The shredding machine crumbles the sheets, pulling them apart, but not grinding them. This leaves fluffy crumbs.

The third step is aging the alkali cellulose crumbs. The crumbs are placed in steel containers under controlled temperature. During the aging of the crumbs, the cellulose undergoes a chemical change as a result of its sodium hydroxide content.

The fourth step is xanthation. The crumbs are placed in huge rotating churns and blended with carbon bisulfide under exact temperature control. This converts the crumbs to cellulose xanthate, which is bright orange in color.

The fifth step is the preparation of the spinning solution. Sodium hydroxide solution is added to the cellulose xanthate in

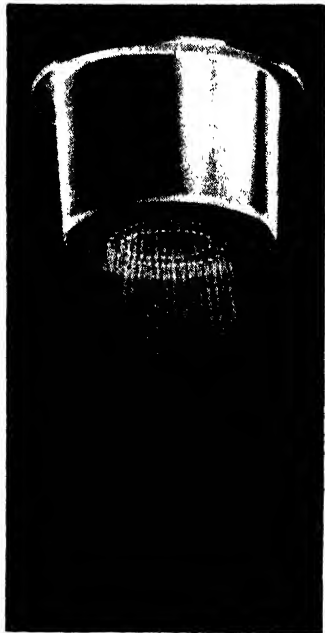
huge blending tanks. At this point the degree of luster desired in the finished filaments is permanently fixed. If high luster is wanted, the blended solution is used without further treatment. If a dull appearance is desired, a special pigment or delustrant is added.

The sixth step is the aging or ripening of the spinning solution. It is allowed to ripen for a fixed time to bring it to the right condition for spinning.

The seventh step is filtration. In precision built presses, all foreign matter is removed by thorough filtering.

The eighth step is the spinning of the rayon. The spinning solution is pumped through a spinneret which is immersed in a hardening bath. (The spinneret is a cap of special metal about half the size of a dime, in which there are tiny holes almost invisible to the naked eye.) As the spinning solution emerges from the holes in the spinneret into the hardening bath, it coagulates into fine filaments. The number of filaments is determined by the number of holes in the spinneret. A single spinning machine consists of many spinnerets immersed in a trough through which the hardening bath flows.

In the production of continuous filament rayon yarn, the filaments as they leave the hardening bath are carried up over a rotating glass wheel and guided down into a whirling collecting bucket. The bucket, which rotates at high speed, imparts a twist to the yarn, and forms it into a cake. The cake of yarn is then



*Courtesy E. I. du Pont
de Nemours & Co., Inc.*

FIG. 45. Type of spinneret used in the manufacture of viscose rayon. Viscose solution is extruded through tiny orifices forming individual filaments which together make the rayon thread.

washed and dried, and is ready for winding into cones or other forms desired by the textile mills.

Cellulose Acetate Process. Purified cellulose is steeped in acetic acid and then allowed to age or mature. The aged pulp is mixed with acetic anhydride, and goes into solution as a new compound, cellulose acetate. The solution is a clear, thick liquid.

After further aging, the cellulose acetate is precipitated in the form of pure white flakes by running the thick liquid into water. The flakes are then washed and dried.

Next, the flakes are dissolved in acetone to form the spinning solution, which is clear and has about the same consistency as molasses syrup.

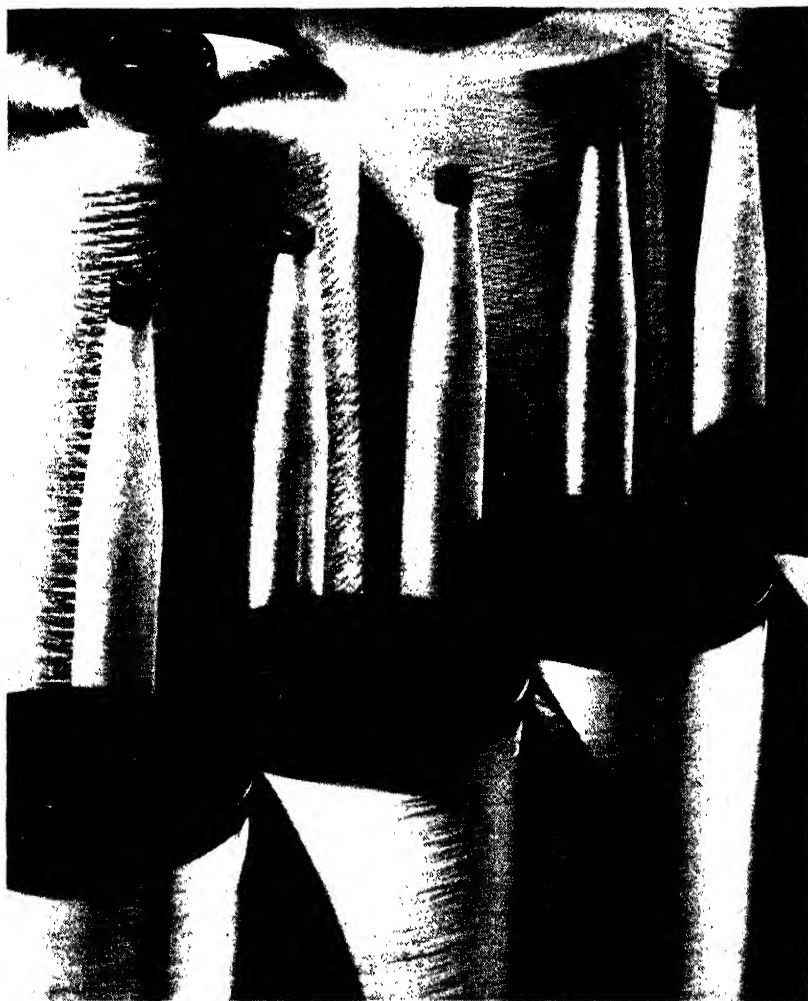
As in the case of the viscose process, the spinning solution is forced through holes of a spinneret to form filaments of rayon. From the holes of the spinneret, the solution falls through a shaft containing warm, humid air. The acetone evaporates, leaving continuous filaments of acetate rayon.

The collected filaments issuing from the spinneret are given a slight twist, and the resultant continuous filament yarn is wound into the various forms required by the textile mills.

Cuprammonium Process. Cellulose is dissolved in a solution of copper sulfate and ammonium hydroxide. The solution is then aged and filtered, after which it is ready for spinning. The spinning solution is pumped through a spinneret. As the tiny streams pass through the hardening bath, they solidify in the form of fine filaments. After the yarn is dried, it is ready for use. During the process the filaments are properly stretched.

IMPROVEMENT IN THE QUALITY OF CONTINUOUS FILAMENT RAYON

Rayon has undergone an almost continuous improvement in quality since its introduction. This is, of course, a natural consequence of its being a man-made fiber. Although improvements in the quality of rayon yarns have been definite, only a few of them can be measured quantitatively. For certain properties,



Courtesy Tennessee Eastman Corporation

FIG. 46. Continuous-filament acetate rayon yarn, as it comes from the spinneret, is uniformly smooth and unbroken. It is pure white, either lustrous or dull, and is wound on cones, cops and spools, for use by textile mills.

quantitative data can be given but for others general observations must suffice.

Tenacity. One of the most important properties of a textile fiber is tenacity, and in this property rayon has undergone marked improvement during the past 25 years. The average tenacity of 150-denier viscose-rayon yarn made by one of the large United States producers in the period 1920 to 1945 is shown in Table 12.1. About half of all the viscose yarn produced is in the 150-denier size, and the strength data given here are considered typical for most of the viscose yarns produced in large quantities.

TABLE 12.1. APPROXIMATE TENACITY OF FIRST-QUALITY
150-DENIER VISCOSE-RAYON YARN MANUFACTURED
IN THE U. S. *

<i>Year</i>	<i>Dry</i> (gms./denier)	<i>Wet</i> (gms./denier)
1945	2.0	1.0
1937	2.0	1.0
1934	1.8	0.8
1925	1.6	0.7
1920	1.5	0.5

* Source: *Bulletin AIC-64*, U. S. Dept. of Agriculture, Southern Regional Research Laboratory.

Although the strength of standard quality viscose rayon yarns has remained about the same since 1937, special high-tenacity types have since become commercially important. These have considerably higher strength than the strongest yarns formerly available. High-tenacity viscose rayon has a dry strength of about 3.6 grams per denier and a wet strength of about 2.4 grams per denier, and the medium-tenacity viscose type has corresponding strengths of approximately 3.0 and 2.0 grams per denier. Production of these types of rayon has expanded rapidly.

Progress also has been made in increasing the strength of acetate-rayon yarns, but their tenacity is still somewhat lower than that of comparable viscose yarns. A special type of rayon made

by stretching and chemically modifying (saponifying) acetate rayon is, however, the strongest rayon manufactured, having a dry tenacity as high as 7.0 grams per denier and a wet tenacity as high as 6.0 grams per denier. Although unusually strong, this type of rayon elongates or stretches comparatively little before breaking. Only limited quantities have been produced thus far (see Fortisan).

TABLE 12.2. DRY AND WET TENACITY AND ELONGATION OF MANUFACTURED FIBERS, AND OF COTTON, WOOL, AND SILK * †

Fiber	Tenacity		Elongation at break	
	Dry (gms./ denier)	Wet (% of dry)	Dry (%)	Wet (%)
Manufactured Fibers:				
Rayon, viscose, regular	1.8-2.1	44-54	16-20	18-25
Rayon, viscose, semi-high tenacity	2.7-2.9	62	16-20	20-27
Rayon, viscose, high tenacity	3.4-3.6	61-65	9-19	14-22
Rayon, cuprammonium	1.7-2.3	55	10-17	17-33
Rayon, acetate, reg.	1.2-1.6	56-68	22-30	29-38
Rayon, saponified acetate	4.8-7.0	71-88	6	6
Nylon, regular	4.5-4.8	84-90	18-22	12-30
Nylon, high tenacity	6.0-7.0	84-90	11-17	12-30
Vinyon, regular	2.0-2.4	100	33	33
Vinyon, "HST"	3.5-4.4	100	16	16
Vinyon E	0.2	....	400	....
Saran	1.1-1.7	100	20-30	20-30
Casein	0.6	35	20-27	120
Soybean	0.6	30	30	70
Glass	6.5	97	2-3	1-2
Natural Fibers:				
Cotton, American Upland	3.0-4.9	110-130	3-7	....
Cotton, American Egyptian	4.2-5.5	110-130	3-7	....
Cotton, Sea Island	4.4-6.3	110-130	3-7	....
Wool	1.0-1.5	80-90	30-50	....
Silk	2.8-4.7	75-85	13-20	....

* Source: *Bulletin AIC-64*, Southern Regional Research Laboratory, U. S. Dept. of Agriculture, October 1944.

† Approximate values as compiled from specifications of manufacturers, published data, and laboratory tests.

Tenacities of the various types of rayon, and of certain other fibers used in textiles are compared in Table 12.2. As is indicated,

rayon has a greater dry tenacity than wool, but is generally weaker than cotton, nylon, and better grades of silk. The saponified acetate type constitutes an exception to this rule, being as strong, if not stronger than any other textile fiber. As is also indicated, rayon loses a greater proportion of its strength when wet than any other fiber except the protein fibers. By contrast, cotton is actually stronger when wet than when dry. In comparing the tenacities given in the table, it should be noted that yarns or fabrics made of continuous filament fibers, such as continuous filament rayon, generally make use of a greater proportion of the basic fiber strength shown than do yarns or fabrics made of short staple fibers, such as cotton or staple fiber rayon.

Number of Filaments. The number of filaments in a rayon yarn of any given size is an important determinant of its properties. In general, the greater the number of filaments the more pliant will be the yarn. Increased pliability has many advantages from a manufacturing standpoint, and results in a softer finished fabric with better draping qualities. Furthermore, other things being equal, the greater the number of filaments the stronger will be the yarn and the fabric made from it. These and other advantages accrue from an increase in the number of filaments.

Fifteen or twenty years ago, 150-denier viscose-rayon yarns usually contained less than 20 filaments, whereas the typical 150-denier viscose yarn of today contains at least 40 filaments and frequently 90 or 100. It is reported that a 100-denier viscose yarn is being made with 100 filaments. Similar trends have occurred in acetate yarns, but yarns made by the cuprammonium process have not been appreciably altered in this respect in recent years, having always been composed of a relatively greater number of filaments. Some of the finer cuprammonium yarns are made up of the finest filaments now manufactured.

Elasticity and Elongation. Low elasticity and susceptibility to permanent distortion through stretching have retarded the use of rayon where these properties are of paramount importance, such as in hosiery and some industrial uses. There has been little

change in recent years in either of these properties, in so far as standard grades of rayon are concerned. However, the various types of rayon now manufactured vary widely in their elongation characteristics making possible a much closer adaptation to the requirements of individual uses than was once the case.

Appearance. During its rise in importance as a textile fiber, rayon's silk-like appearance was one of its most valuable assets in competition with other fibers, but in uses where a glossy effect was not desirable, this characteristic was a distinct handicap. From about 1926 to 1931, several processes were developed for producing dull and semi-dull rayons. Some of the earlier processes involved the delustering of the finished yarn or fabric, but today this is usually accomplished by introducing a pigment directly into the spinning solution. The development of these processes greatly extended the competitive field of rayon and has no doubt been one of the most important factors in its increased use.

Dyeing Properties. The chemical properties of rayon are important in connection with the dyeing process. No simple standards can be set up for comparing the dyeing properties of rayon, but they have been greatly improved during the past 10 or 15 years. Modern rayon yarns and fabrics possess greater absorptiveness and dye with more uniformity than their predecessors. Dyeing methods and the dyes themselves have also been improved. There are wide variations in the dyeing properties of the different types of rayon. This has been of considerable advantage in obtaining attractive cross-dye effects in fabrics containing more than one type of rayon or rayon blended with other fibers.

Special Finishes. Very recently there has been an increasing amount of attention given to the treatment of textile fabrics with special finishes designed to alter their normal properties. One of the finishes most widely used with rayon involves the impregnation of the fabric with a synthetic resin, the quantity ranging in weight from 1 to 15% of the weight of the untreated fabric. By means of such finishes, the fabric's resistance to crease may be greatly enhanced. Another desirable property that may be im-

parted to the fabric is the ability to repel water. Some finishes alter the surface appearance of the fabric and other finishes improve its color fastness. Many of these special finishes increase both the wet and the dry strengths of the fabric and consequently improve its serviceability.

Uniformity. While the physical and chemical properties of rayon were being improved, it was also being made more uniform in quality. Commercial rayons have become more uniform in their tenacity, diameter, and denier (all of which are closely related). Likewise, improvements in the techniques of handling rayon in each of the steps of its manufacture into fabrics, especially in those processes in which the material is wet, have resulted in more uniform fabrics. These improvements have enabled the manufacturer to produce fabrics to given specifications with greater certainty and, therefore, with smaller losses. Dyeing properties have also been made more uniform, an obvious advantage.

Educational Program. An important factor in the rapid rise of rayon has been the educational program carried out by the producers in connection with its use. This program has taken two general directions; advertising and the dissemination of information on the care of rayon fabrics.

In the early days, rayon was used largely by textile manufacturers as a less expensive substitute for silk, but through intensive advertising, the manufacturers have made the public aware of the fact that rayon is a textile distinct in its properties from all others. This increased consumer acceptance of rayon and made it possible to market such fabrics on their own merits rather than merely as substitutes. The result was a considerable widening in its field of application.

It is now generally recognized that rayon fabrics require special care in cleaning and laundering, just as silk and wool do, although the care is somewhat different. After rayon was first introduced the average consumer was unaware of this, and articles made from it were often damaged by improper care. This resulted in considerable consumer prejudice against rayon. To correct this,

the manufacturers brought to the public's attention the pertinent facts on the proper cleaning and laundering of rayon fabrics. Laundries and dry-cleaning establishments were provided with the necessary information, with the result that these fabrics are no longer mistreated through lack of knowledge of the proper methods.

HIGH-TENACITY RAYONS

Some well-known trade names for high-tenacity viscose rayon yarns are the following:

<i>Trade Name</i>	<i>Producer</i>
Cordura	E. I. du Pont de Nemours & Co.
Hygram	Tubize Rayon Corporation *
Super-Narco	North American Rayon Corp.
Tempra	American Enka Corp.
Tenasco	American Viscose Corp.
Tyron	Industrial Rayon Corp.

* Acquired (1946) by Celanese Corp. of America.

Du Pont's Fiber G. Fiber G is a new high-strength viscose rayon yarn under development by the Rayon Division of E. I. du Pont de Nemours & Co., Inc.

It is reported that the new yarn, a result of the adaptation of a new spinning method, has a tenacity of 5 grams per denier, dry, and retains 75% of its strength when wet. The wet strength is given at from 3.5 to 3.7 grams per denier. This is about the same as the dry strength of the high-tenacity viscose-rayon tire yarn.

A low elongation of only 6 to 7% is reported. The low elongation is a feature that Fiber G has in common with other high-strength rayon yarns including the saponified acetate rayon yarns.

The yarn is produced in a viscose yarn manufacturing plant, and a wet spinning method is employed. Yarn sizes are 240 denier with 120 filaments and 1100 denier containing 480 filaments. The 1100 denier would suggest application of the yarn for automobile

tires, while the 240 denier would indicate its possible use in the manufacture of sewing thread.

Because of the superior wet strength of the new yarn, it is quite likely that it will find widest use in the field of industrial textiles. In addition, it may prove useful in the apparel field for such items as bathing suits, shoes, and corset nets.

Dyeing of High-Tenacity Rayons. In the case of the high-tenacity rayons, the alteration of the physical structure of the filament caused by the stretch spinning lowers the affinity for dyes to approximately 75% of that of ordinary viscose rayon. The same classes of dyes can be used for the dyeing of high-tenacity rayons, although it is difficult to obtain heavy shades with most dyes. Naphthols have proved to be most satisfactory for producing full shades on this type of material.

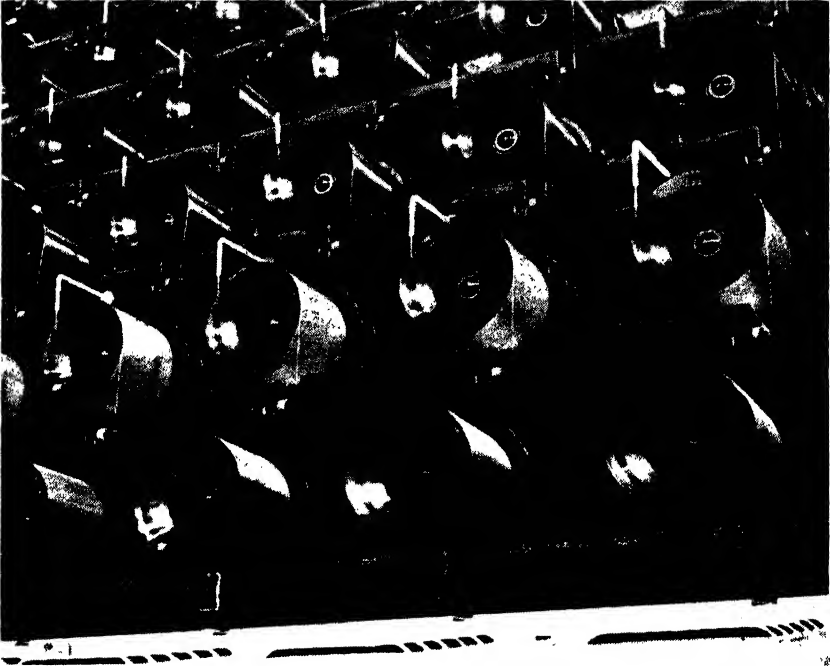
CONTINUOUS SPINNING AND PROCESSING OF VISCOSE RAYON

Until 1938 there had been but two generally accepted methods of producing viscose rayon—the spool system and the pot system. In that year Industrial Rayon Corporation introduced a new method—the continuous spinning and processing of viscose yarn. Development work on this process had started in 1932.

The exacting chemical controls of rayon manufacture assured a high degree of uniformity up to the point where viscose coagulated into filaments of yarn. Beyond that point, yarn produced by either the pot or spool system was subjected to all the irregularities and inconsistencies of bulk processing and repeated physical handling of the yarn. The continuous process was developed to permit treatment of individual strands of yarn and to eliminate handling of the yarn as it moved through all of the required processing steps.

A problem was the need for a means of transporting the yarn through successive processing stages in a manner that would permit the application of processing solutions to individual strands for a sufficient length of time to permit thorough treatment.

Early work was concentrated on a thread advancing reel which could carry yarn across its surface without ever winding on itself or touching any other part of its own length. This reel is made of two cylindrical cages. These cages are assembled so that the



Courtesy Industrial Rayon Corporation

FIG. 47. Rayon yarn is completely processed by individual thread treatment as it travels from stage to stage over these thread advancing reels on which it is washed and treated. The reels transport the yarn so that no thread touches any other thread. Processing solutions fed through glass tubes are evenly and thoroughly applied.

bars of one are between the bars of the other and so that the axes of the cages are inclined with respect to one another.

They do not rotate about the same center, although they operate together when rotating. The effect of these cages assembled in this relation is to cause a thread led onto the reel at the back end to advance along the bars in a helical path and drop off at the forward end.

Many types of materials were tested for this reel during the experimental stages. It not only had to resist action of chemicals used in processing yarn but had to be produced to exact tolerances so that the speed of travel of the yarn would not be affected. For the spinning and processing operations a reel of molded plastic was devised; for drying, an aluminum reel of similar construction was produced.

Development of the machines on which these reels were to perform their thread advancing function also presented many problems to combine the necessary spinning, processing and drying stages. By tiering them, compactness was gained, floor space was saved and ease of servicing provided at all three stages. An A-shaped structure with three operating levels was designed and erected for pilot operation.

In continuous process production, viscose department operations follow the same basic procedures employed in plants using either the conventional spool or pot system. It is not until the filtered viscose is pumped to the spinning machines that the radically different methods come into use.

In the conventional methods the yarn is wound into a package as it is drawn out of the spin bath. This package, either a spool or a cake, is removed when full and passed through a series of processing operations. In continuous spinning and processing the yarn is never wound into a package until it is fully processed.

As the yarn emerges from the spin bath on the top level of the continuous process machine, the filaments are drawn up to the first of the thread advancing reels. Here the yarn is advanced from the back to the outer end and then dropped through a slot to the processing section below.

On the process level eight more plastic reels carry the yarn through a like number of processing treatments for washing, desulfurizing, bleaching and conditioning. These solutions are applied through glass tubes placed immediately above the individual reels and flow onto the yarn as it passes over the surface of the reels in a single layer. As a result, every inch of every filament receives the same uniform treatment.

From the last processing stage the yarn drops into an enclosed compartment which houses the aluminum drying reel. Internally heated by either circulating hot water or steam, this reel thoroughly and uniformly dries the yarn as it passes between its extremities.

At the final stage, the yarn is given a slight twist as it balloons over cap twisters onto plastic bobbins which hold approximately 3 lbs. of yarn. This is fully processed yarn, requiring only re-winding onto cones before shipment to textile mills.

Each continuous process machine has 200 spinning positions, 100 on each side of its A-shaped frame. Each position is serviced by ten reels to carry the yarn from the spin bath, then through processing and drying—a total of 2,000 reels per machine to deliver yarn.

Although there is a reduction in the time required between the spin bath and the final processing of the yarn as compared with conventional methods, an advantage of the continuous process lies in the high quality yarns it produces.

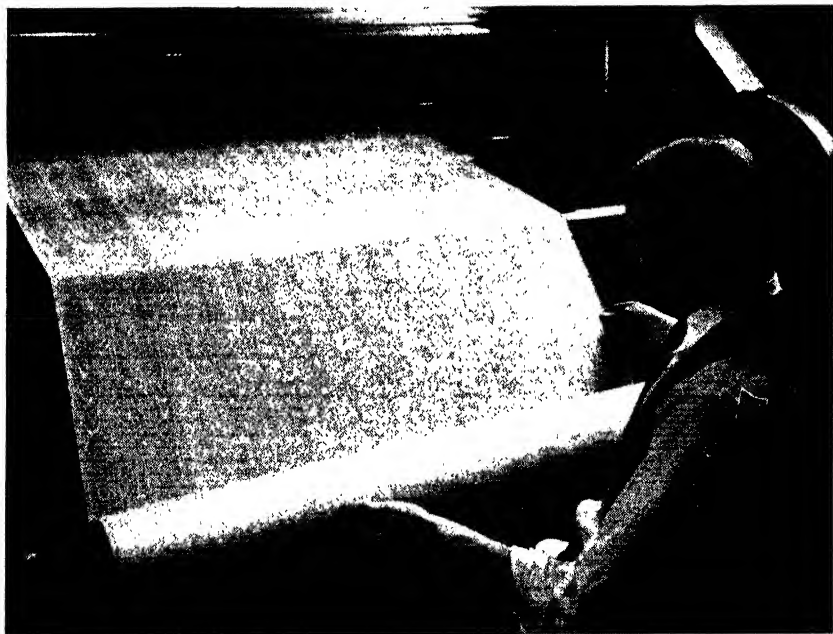
The number of knots and broken filaments in the final cone package is substantially reduced because of the ability to process the strands in continuous lengths and the elimination of physical handling of the yarn. Even application of processing solutions by individual thread treatment assures yarn uniformity not only within a package but from package to package. Machine controlled accuracy during drying maintains this uniformity in luster, denier and strength as well as in dyeing properties.

ACETATE RAYON

Acetate rayon possesses a degree of softness and resilience which gives fabrics a desirable drape, hand and resistance to wrinkling. Its low swelling power imparts increased dimensional stability to washable fabrics and also accounts for its resistance to moisture-borne stains and consequent ease of cleansing. While its heat-softening property necessitates care in ironing fabrics made of cellulose acetate, this property is utilized in the production of

permanent moirés and pleats, and in the manufacture of laminated fabrics and fused-edge ribbons.

Like viscose rayon, the acetate loses strength when wet, but its loss in strength is less than that of viscose and is completely regained on drying. Acetate rayon dries more rapidly than viscose, because it absorbs considerably less moisture.



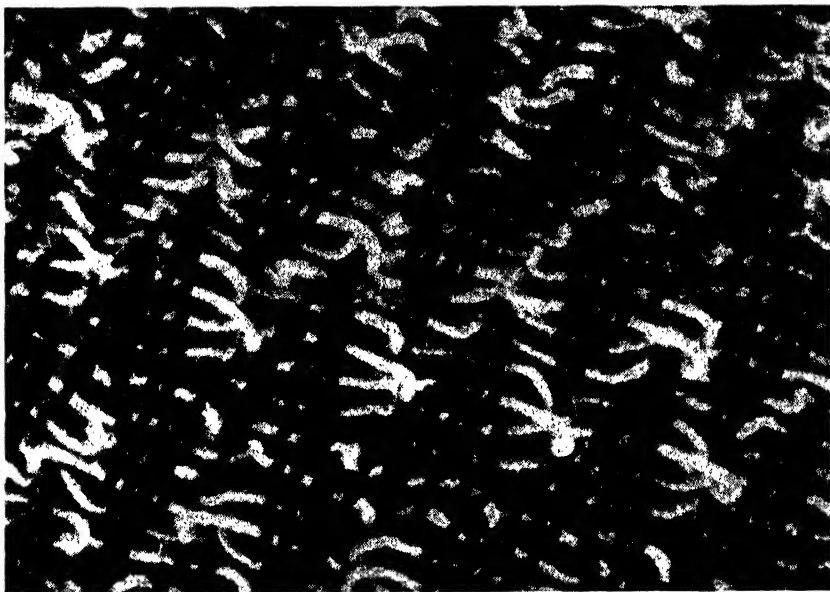
Courtesy Oelanese Corporation of America

FIG. 48. This shows the final operation in the production of moiré fabric, the pattern of which is permanent to moisture or actual immersion in water.

Cellulose acetate yarns and fabrics, in contrast with those made from regenerated rayons, are highly resistant to mildew. Where mildew does occur, it is usually found to be living on extraneous matter rather than on the fiber itself. The yarns are also excellent electrical insulators combining low moisture absorption, high electrical resistance, high dielectric constant and high dielectric strength in addition to having a low tendency toward causing corrosion under conditions of voltage stress. The

fact that they may be sealed by application of solvent or heat is especially valuable in the sealing of coils.

Dyeing Properties. A special type of dyestuff had to be developed for cellulose acetate rayon. A complete range of shades having good fastness has been available for many years, and new



Courtesy Tennessee Eastman Corporation

FIG. 49. Fabrics of acetate rayon blended with silk, wool, cotton or viscose rayon can be dyed in two-tone effects, as shown. The process, "cross-dyeing," is possible because there are dyes for acetate rayon which do not affect other fibers, and dyes for other fibers which acetate rayon resists.

dyestuffs, generally of improved fastness, continue to appear on the market. In addition, a method of applying vat colors without impairing the cellulose acetate has recently been announced. Many of these vat colors are exceptionally fast to light and to washing. The use of selected acid or wool dyestuffs through the action of a swelling agent is now being carried out commercially and results in improved fastness, particularly to washing. The fact that cellulose acetate does not dye with wool or cellulosic

dyestuffs under normal conditions has been utilized in producing cross-dye and other color effects.

Certain fluorescent dyestuffs can be applied directly to cellulose acetate yarns and fabrics with full retention of brilliance. This property was utilized during the war in the production of signal panels, identification panels, and signal flags for the armed forces. A substantial yardage of fluorescent dyed cellulose acetate satins was used for such purposes.

High-Impact Acetate Rayon. This type of acetate rayon, also known as high-elongation acetate rayon, was developed during the war by Tennessee Eastman Corporation specifically for cargo or aerial delivery parachutes, when it appeared that the supply of high- and medium-tenacity viscose rayon would be insufficient to meet the requirements for parachutes of this type.

High-impact acetate rayon has a strength approximately equal to that of regular acetate rayon—namely, about 1.4 grams per denier, but its breaking elongation is 40 to 45%, which is approximately twice as high as that of regular acetate rayon. Consequently, although the strength of a fabric made of high-impact acetate rayon is no greater than the strength of a similar fabric of regular acetate rayon and considerably less than that of a similar medium- or high-tenacity viscose fabric, its impact resistance or shock loading, which is a function of the work required to rupture the fabric, has been shown by tests to be equal or better than viscose fabrics. Resistance to stretching under small loads is very close to that of regular-tenacity acetate rayon, so that the yarn can be handled with normal tensions during processing. Heat, especially in conjunction with moisture, affects adversely the high elongation and the yarn was therefore woven without size.

Several million pounds of this type of yarn were made and used in the canopy fabric of aerial delivery parachutes. In general, excessive gain, or no recoverable stretch, is not desired in civilian fabrics, but it is quite possible that this property of the high-impact or high-elongation acetate rayon will be of value for specific industrial or apparel applications.

CUPRAMMONIUM RAYON

Although the viscose and the acetate processes account for the great bulk of rayon produced, some is manufactured by the cuprammonium process. The cuprammonium rayon made in the United States is best known by the trade name "Bemberg." Cuprammonium rayon is characterized by the exceptional fineness of the filament and its strong affinity for dyes. It is used in hosiery and sheer fabrics. Since the fabrics made of it generally are not expected to withstand severe exposure and wear, it is largely dyed with direct and after-treated direct colors in substantially the same manner as viscose rayon. It takes up the dyes more rapidly than viscose rayon or mercerized cotton and much more readily than natural cotton.

American Bemberg Corporation has recently developed a new very fine denier yarn. It is reported to be a 30 denier yarn with 75 filaments.

HELANCA

An interesting new type of viscose rayon, known as "Helanca," was used extensively in Switzerland during the war as a substitute for wool. It is a yarn mechanically and chemically treated to produce a permanent wool-like effect. It is said to be superior to wool in resistance to shrinkage, as it does not felt. It is not attacked by moths nor damaged by alkalies. Late reports (1946) indicate that the new yarn is still in demand, notwithstanding the return of wool to the market.

Development and Manufacture. In the early 1930's, Heberlein & Co., A. G., Wattwil, Switzerland, produced rayon fibers having a crimp similar to that of wool. Under the original process, continuous filament rayon yarns were given an excessive twist, steamed under pressure in this over-twisted state, and then de-twisted. However, the crimp obtained was not permanent. After considerable research work, it was found that the crimp imparted by the original mechanical operation could be made permanent by chemical treatment with formaldehyde. The crimp

was also fixed by allowing the fibers to swell while the yarn was in an over-twisted state. A recent development involves the improvement of the mechanical part of the process by combining the two expensive twisting operations in one step.

Since 1936, the trade name, "Helanca," has been used to designate the product made by this process.

Properties. The characteristic crimp of the fiber gives it a very soft and full "feel." The crimp is permanent and is not lost even after repeated laundering. The fiber can be readily distinguished from rayon by its wool-like appearance, and under the microscope the typical curliness of the individual filaments can be observed.

According to tests made in Switzerland, Helanca has an insulating capacity very close to that of wool. If wool be given an index of 100, then Helanca would have a value of 89, compared to 35 for viscose rayon. The amount of insulating air volume within comparable samples of textile yarns was as follows: Helanca, 82-92%; wool, 82-90%; viscose rayon, 68%.

The swelling capacity of Helanca is far below that of other cellulosic fibers. In cuprammonium hydroxide solution, Helanca swells very little, while viscose rayon is quickly dissolved.

Helanca yarns may be dyed prior to or during the crimping process and it is noteworthy that fast and vat dyes can be applied.

Compared with viscose rayon, Helanca has better wet strength as well as greater elasticity. Like other cellulosic fibers, it is inflammable.

While Helanca is very similar to wool in many respects, it is superior in certain characteristics. Helanca is mothproof, as well as fast to alkali and chloride. Textile goods made of the yarn are therefore not impaired by washing, do not shrink, and have no tendency to felt.

Applications. Helanca yarns are available in a wide variety of colors. They are used to make knit goods for infants' wear, underwear, and dresses. They are also used to make woven goods

such as overcoat fabrics, blankets, scarfs, and similar articles. A promising field is in carpet and velvet manufacturing in which the voluminous character of the yarn would be advantageous.



FIG. 50. Wool not washed.

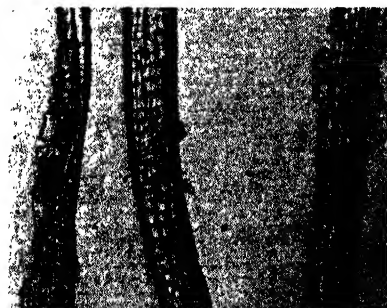


FIG. 51. Wool after an alkali wash.



FIG. 52. Helanca not washed.



FIG. 53. Helanca after the same alkali wash.

The Helanca process is applicable to all types of manufactured fibers, both continuous filaments and staple fibers. In addition to the regenerated cellulosic fibers such as viscose and cuprammonium rayon, cellulose acetate rayon, as well as nylon and other synthetic fibers, can be treated by the process.

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Courtesy Tennessee Eastman Corporation

FIG. 54. This shows crimped acetate rayon staple, which varies in length from three quarters of an inch to nine inches.

CHAPTER XIII

Rayon Staple Fiber

SUMMARY

Commercial development of rayon staple fiber has been one of the most important factors in the rapidly increasing use of rayon during the last 15 years.

Staple fiber can be produced and sold at a lower price than continuous filament rayon for several reasons. It can generally be made in larger unit quantities and it is less expensive to inspect and package. Moreover, scrap from continuous filament operations can be utilized in making staple fiber. Although staple fiber subsequently requires more costly processing to convert it into yarn suitable for weaving or knitting than does continuous filament rayon, the former still has an advantage in cost. It also has the advantage over continuous filament rayon of being suitable for processing on cotton and wool manufacturing equipment, which makes up the great bulk of all textile manufacturing facilities. By processing staple fibers either unblended or blended with other fibers on such machinery, it is possible to obtain entirely different types of yarns and fabrics from those which can be made by using continuous filament rayon.

VERSATILITY OF RAYON STAPLE FIBER

Rayon staple fiber is made by drawing the filaments from many spinnerets together without twisting and then cutting them into definite lengths. The length and diameter of these fibers can be varied, according to the purpose for which the yarn is to be used. The fibers are washed, bleached and dried in a con-

tinuous operation. Then they are fluffed up, baled, and shipped to the textile mill. There the staple fibers are carded and combed back into parallel arrangement again. They can be spun into yarns on the cotton, wool, and worsted spinning machinery, after which they are termed spun rayon yarns.

TABLE 13.1. ESTIMATED CONSUMPTION OF RAYON STAPLE FIBER IN U. S.*

<i>Year</i>	<i>Quantity (millions of lbs.)</i>	<i>Percentage of total rayon consumption (%)</i>
1945	165.1	21.5
1944	165.7	23.5
1943	161.9	24.7
1942	152.0	21.5
1941	130.1	23.5
1940	93.3	19.4
1939	99.0	21.6
1938	55.3	16.8
1937	37.6	12.3
1936	24.8	7.7
1935	6.4	2.5
1934	2.1	1.1
1933	5.4	2.5
1932	3.3	2.1
1931	1.6	1.0
1930	0.9	0.7
1929	1.9	1.5
1928	0.4	0.4

* Source: *Rayon Organon*.

Almost all the improvements which have been discussed in the case of continuous filament rayon have also been made in staple fiber since its introduction. Its strength, uniformity, and finishing and dyeing properties have all been improved. The development of finishes that enhance the crease resistance and wet strength of spun rayon fabrics has been highly important. The luster of staple fiber, of course, is controlled just as it is with continuous filament rayon. In addition, some success has been achieved in imparting a permanent crimp or waviness to staple fiber rayon.

Coincident with these improvements, the variations in denier, length, and luster, etc., have been greatly widened. For example, a few years ago there were only two types of rayon staple fiber—1.5 and 3 denier—and today there are between 50 and 100 types, making possible better adaptation to the requirements of specific products. In addition, special types of staple fiber were introduced for specific purposes. For instance, one type is manufactured with a pronounced crimp and with a large diameter and smooth cross-sectional outline, for use in floor coverings, upholstery, and similar fabrics where resiliency and resistance to soiling are required. Another type, designed for use in the worsted industry, has a varied staple length to complement the fiber lengths of the wool with which it is later blended.

The versatility of rayon staple fiber is almost unlimited. It is used not only in women's dress and suiting fabrics, but also in men's suits, shirts, pajamas, handkerchiefs, neckties and other articles of men's wear, in blankets, towels, tablecloths, rugs and carpets, diapers, optical wiping cloths and numerous other products.

Much work has been done in recent years to develop methods by which rayon fabrics could be made resistant to shrinkage. This means that such fabrics should not shrink more than 1 to 2% when washed. Several means of attaining this objective have been developed, including a method for Sanforizing rayon fabrics. This should make possible wider use of fine spun rayon fabrics.

FINE VISCOSE RAYON STAPLE FIBERS

The recent development of fine-denier high-strength viscose rayon staples makes possible the production of new fabrics that are light in weight, soft to feel, and silky in character. In this connection, the introduction of 1.0 denier and 1.25 denier rayon staple fibers by American Viscose Corporation is of considerable interest.

The 1.0 denier fiber is produced in appropriate standard lengths suitable for the different spinning systems on which it

is used. Basically, it is said to permit the spinning yarns of far finer sizes than heretofore possible with standard type rayon staple fibers. That is, the 1.0 denier filaments are sufficiently fine so that the spinner can make yarns of 25 to 30% less weight than was previously possible.

In addition, the 1.0 denier staple increases materially the strength of spun rayon yarns and fabrics as compared with the yarns and fabrics made with standard type viscose rayon staple fibers. Tests have also demonstrated that the new fiber provides superior creping qualities in fabrics made with high-twist spun rayon yarns.

Commercial applications include flat knit fabrics, simplex glove fabrics, tricot knit dress goods, fine broadcloths, foundation fabrics, handkerchiefs, blouses, gowns, sheer dress fabrics, men's shirtings, and men's underwear cloth. These are available in constructions featuring yarns as fine as from 50/1 to 80/1 and 100/2 cotton counts.

The 1.0 denier rayon staple has been spun experimentally in 100% content yarns as fine as 200/1 and 300/1 cotton counts, a size finer than that usually spun of the longest length cotton staples by American mills. In such fineness, 1 pound of the yarn would be approximately 150 miles long.

It is claimed that yarns as fine as 100/1 cotton count can be commercially spun from the 1.0 denier staple, and yarns as fine as 70/1 cotton count can be made successfully from the 1.25 denier staple.

In addition to the increased range of yarn sizes that can be made with these new finer staples, they offer new possibilities in the coarser yarns. In these, an unusually soft touch can be obtained, an effect that is highly desirable in many types of fabrics. These coarse yarns possess added strength because of the greater number of fibers in the yarn cross section.

The 1.0 denier and 1.25 denier staple fibers can be used in blends with fine natural fibers, such as Sea Island, Pima and Egyptian cotton, fine wools or silk.

The introductory price of 1.0 denier viscose rayon staple, as announced by American Viscose Corporation early in 1944, was 26¢ a pound.

TABLE 13.2. PRINCIPAL USES OF SPUN RAYON YARNS*

<i>Rayon staple fiber (denier)</i>	<i>Yarn size (cotton count)</i>	<i>Principal uses</i>
1.0	100/1	Fine shirtings, sheer dress goods, blouses, handkerchiefs, neckwear, laces, hosiery
1.0 to 1.25	70/1	Handkerchiefs, blouses, fine dress goods, crepes, pajamas, curtains, lamp shades, neckwear, glove fabrics, hosiery
1.0 to 1.5	50/1	Printed and plain dress fabrics, blouses, bedspreads, jacquard draperies, scarfs, children's dresses, underwear, lingerie, decorative suiting yarns, shirtings
1.0 to 3.0	24/1	Men's and women's suitings, sport shirtings, upholstery, diapers, towels, flannels
1.0 to 5.5	11/1	Drapery goods, upholstery, summer suitings, towels, seat coverings, tablecloths, women's sport fabrics, blankets, half hose

* Source: American Viscose Corp.

VARIED-LENGTH STAPLE FIBER

A varied-length staple fiber, called "Fibro," has been developed by American Viscose Corporation. The distinguishing feature of this fiber is that it is cut in such a manner that, in fiber length dispersion, a rayon top made from it closely resembles a worsted top.

The concept of varied-length rayon staple was the outgrowth of extensive observation of the characteristics and behavior of both natural and man-made fibers. The original development was planned as an improvement which would aid worsted blending. An advantage of the new product is a correctly proportioned blend composed of hundreds of different fiber lengths having a range for which the maximum and minimum lengths are predetermined. This eliminates a concentration of any one

length, a factor which is important for thorough blending, particularly on the worsted system.

The two benefits claimed for varied-length staple fiber are better blending with wool and a more evenly spun yarn. The better blending of fibers has obvious advantages for cross-dye effects or stock-dyed mixtures. Yarn evenness leads to better weaving efficiency and fewer imperfections in the fabric.

It is reported that varied-length staple fiber is finding wide acceptance in the woolen and blanket industries.

KOHORN WOOL TYPE STAPLE FIBER

Oscar Kohorn & Co., Ltd., has developed a wool-imitation staple fiber which combines the properties and advantages of natural wool with the low cost and versatility of the viscose rayon fibers. It is known as the Kohorn Wool Type Staple Fiber. Among its wool-like properties are:

1. A broken and rough surface, approximating the scaly texture of the natural wool fiber.
2. A cross section with a horseshoe shape, containing an air-enclosing (insulating) space running throughout the length of each individual fiber.
3. A permanent crimp much more pronounced than that of cotton, and equal to that of wool.

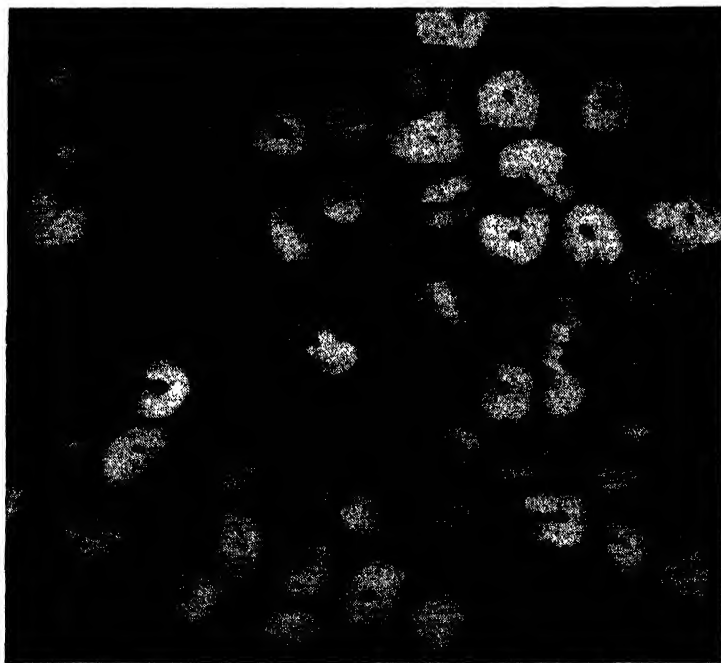
The Kohorn fiber has a higher elasticity than the average viscose fiber and is stronger than natural wool in the dry state and as strong as wool in the wet state. The fiber can be produced in any denier to blend with the particular type of wool used, and its physical properties can be controlled to make it suitable either for ordinary spinning and weaving, or for felting.

The fiber has the advantage of being naturally dull without requiring the use of delustering agents. These properties are obtained simply by a modification of the standard viscose process. No special chemicals or equipment are required to produce this wool-type staple fiber.



Courtesy Oscar Kohorn & Co., Ltd.

FIG. 55. Longitudinal view of wool-type staple fiber.



Courtesy Oscar Kohorn & Co., Ltd.

FIG. 56. Cross-sectional view of wool-type staple fiber.

Manufacturing cost of this fiber is the same as that of standard viscose staple fiber.

Fabrics produced from Kohorn fiber, either in 100% form or blended with wool, have wool-like qualities at a cost far below that of fabrics produced from virgin wool.

The Kohorn process was perfected during the years before the war and was first introduced on a commercial scale in six Japanese staple fiber plants. It proved highly successful there, and in 1941 a plant was about to be established in America, but had to be deferred on account of the war.

MANUFACTURE OF RAYON TOW

A new form of rayon, rayon tow, is made by the viscose process and was introduced to the trade in 1941. Rayon tow is a collection of several thousands of continuous rayon filaments having the general appearance of untwisted rope. The diameter of each filament and the number of filaments making up the tow are accurately controlled. The tow should not be confused with rayon staple fiber (short lengths) nor with regular continuous filament rayon.

The early steps of rayon tow manufacture are the same as those taking place in the production of regular rayon staple fiber. The viscose is extruded through spinnerets having several thousand holes each, and the filaments from a number of spinnerets converge to form a single rope. This is carried through the usual washing, desulfuring, and drying steps, but is not chopped up and the filaments do not lose their parallel arrangement as in the case of regular staple fiber. Tow with straight filaments is wound on cardboard tubes, whereas the tow with crimped filaments is packaged in cases. The individual parallel filaments which make up rayon tow can be obtained in denier sizes of 1.5, 3.0, 5.5 and 10.0.

“Tow-To-Top” Process. New methods, known as “tow-to-top” conversion of continuous filaments, have been developed for converting fibers into spun yarn without going through the com-

plicated and costly operations of carding and combing. The new processes lend themselves particularly to manufactured fibers, and in this field they represent a revolutionary step.

J. L. Lohrke and H. H. Perry (the "Perlock Process"), N. S. Campbell (the "Campbell Process"), and Pacific Mills, Worsted Division, have developed methods of "tow-to-top" cutting. These operations, in general, consist of breaking or cutting the continuous rayon filaments of the tow into staple fiber lengths and converting them into tops without disturbing the original parallel alignment of the filaments. All three processes are being used for commercial production of rayon top, and it is claimed that the waste from the machines is much lower than that obtained during the carding and combing operations.

The uses for rayon top produced by these simplified methods are fully as diversified as those for top made by the usual processes. They range from ribbons to carpets and include blends with wool for women's and men's apparel. Another advantage in the case of rayon tow that appears to be indicated is that it is easier to apply water repellents or other treatments to the tow, in a continuous process, than to treat the staple fiber in batches.

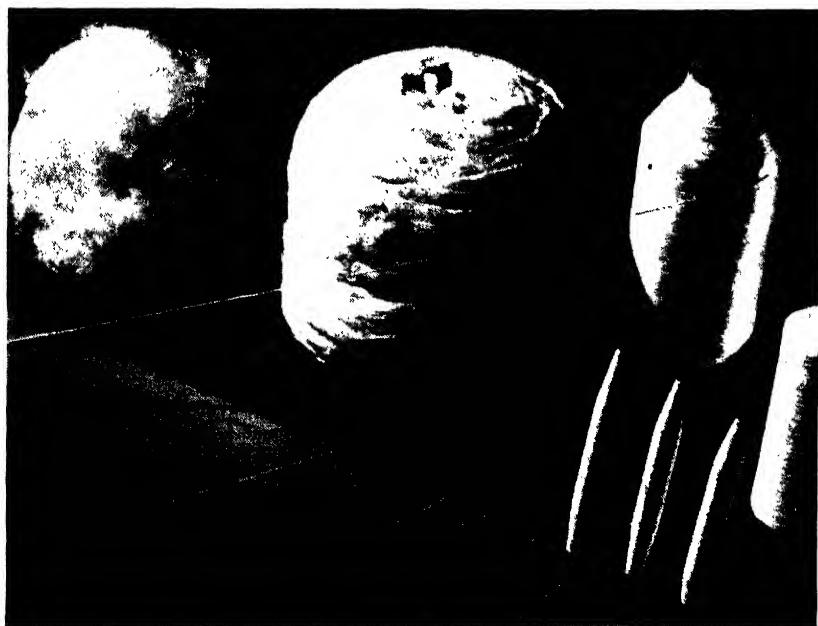
ACETATE RAYON STAPLE FIBER

The use of cellulose acetate staple fiber in yarns, either alone or blended with other fibers such as wool, cotton, and viscose rayon, has been expanding even more rapidly than that of viscose rayon staple.

Some acetate staple goes into all-acetate fabrics, but the greater part of total production is used in blends with viscose staple. The acetate contributes improved hand and wrinkle resistance to the finished fabric and it also reduces shrinking and stretching. The use of acetate rayon staple lends additional variety to rayon yarns and fabrics due to cross-dye effects. Applications include men's suitings, particularly in summer weights; sportswear for men, women, and children; women's dress goods, and lounging robes.

Blends of cellulose acetate and wool are used in men's wear fabrics, sweaters and sweater yarns, women's suitings and

topcoat fabrics, blankets and women's shoes. Very soft fabrics can be made from such yarns and the natural felting and shrinking properties of the wool are modified to the extent that less shrinkage takes place in laundering than would occur in similar articles made entirely of wool.



Courtesy Tennessee Eastman Corporation

FIG. 57. Rayon staple fiber is packed in a compact mass somewhat like cotton or wool. The yarn has a porous, fuzzy appearance quite different from that of smooth continuous-filament yarn.

Blends of acetate staple and cotton are used for men's sportswear, raincoat fabrics, women's dress fabrics, suitings and topcoats, shoe fabrics, and men's hose.

A popular new application of acetate staple is in bed comforters and pillows, where, because of its excellent insulating qualities, it is used to replace down. A related application is its use in warm sleeping bags.

A promising market for acetate staple is considered to be the carpet and rug industry. This market is being vigorously promoted.

SPUN-DYED RAYON STAPLE

Spun-dyed rayon staple, or solution dyed fiber, is available in both the viscose and acetate types of rayon. It is said to offer economies and technical qualities not otherwise obtainable. In making these materials, the dye is introduced into the viscose or acetate spinning solution, which distributes the color uniformly and also gives excellent resistance to fading resulting from sunlight, washing, dry cleaning, atmospheric gases, and crocking. So far the only colors produced have been blacks, blues, and pink (tea rose). It is considered doubtful whether manufacturers will offer such staple fiber in more than a few standard colors.

FUR FIBERS AND RAYON MIXTURE FABRICS

Wool and rayon staple have recently been mixed with fur fibers, such as mink, muskrat, and silver fox. Mixtures made up of 20% fur fibers, 70% rayon, and 10% wool, principally in raw stock blends, have been spun into yarn which gives a non-shedding piece of goods. Although this idea is not new, it has recently been revived. Traub, Lyons & Oppenheim have produced such yarns by a patented "Blendlock" process under the trade name "Natura." These yarns are said to have unusual softness, great resilience and a smooth silky texture and color charm. They have been used principally to make dress goods; also drapery and upholstery fabrics, blanket covers and curtains, sweaters, negligees, blouses, scarfs, gloves, bags, shirts, millinery and show fabrics.

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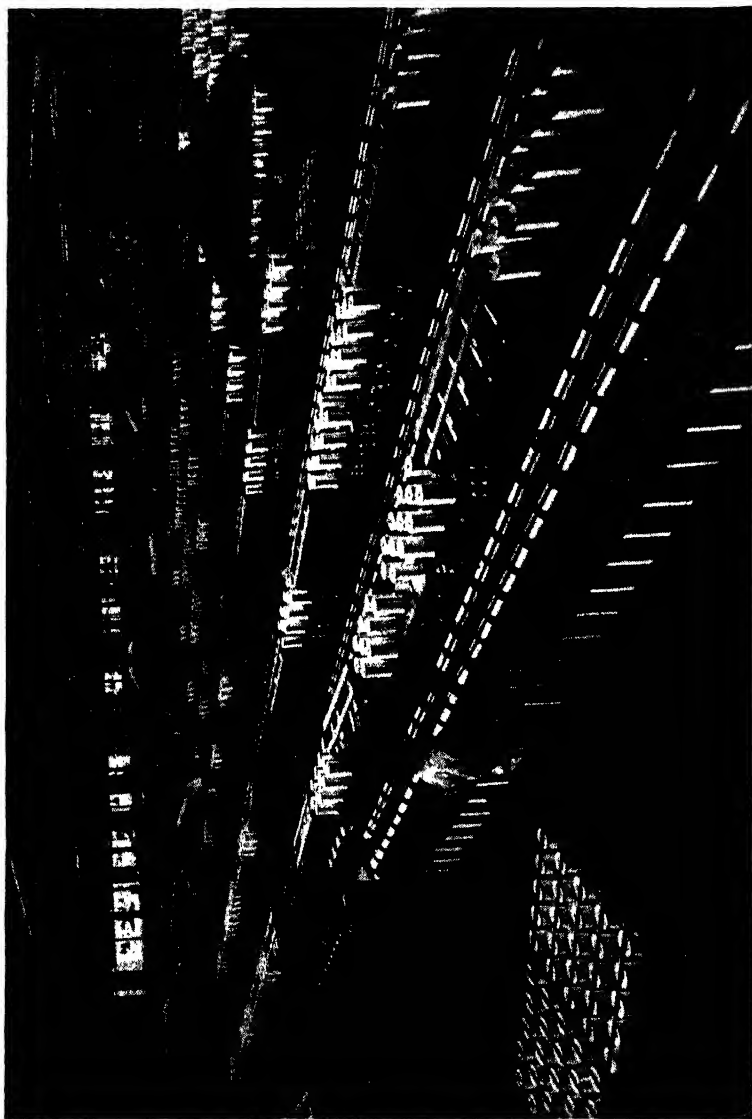


FIG. 38. A view of one of the huge textile sheds at a plant of Celanese Corporation of America. It serves to give some idea of the vast size to which the acetate rayon industry has grown in recent years.

Courtesy Celanese Corporation of America

CHAPTER XIV

Economic Aspects of Rayon

SUMMARY

The great strides taken in recent years in improving rayon and reducing its price have given it a new economic importance. The development of high-tenacity rayon has opened new industrial markets, while expansion in the apparel field has gone steadily forward.

Rayon is now second only to cotton in commercial importance and it is still in a stage of vigorous growth.

Of the three basic processes for making rayon—the viscose, the acetate, and the cuprammonium—the viscose process still accounts for the major portion of output of both continuous filament and staple fiber. However, the acetate process has shown the most rapid growth over a period of years. The cuprammonium process accounts for only a very small proportion of total rayon output.

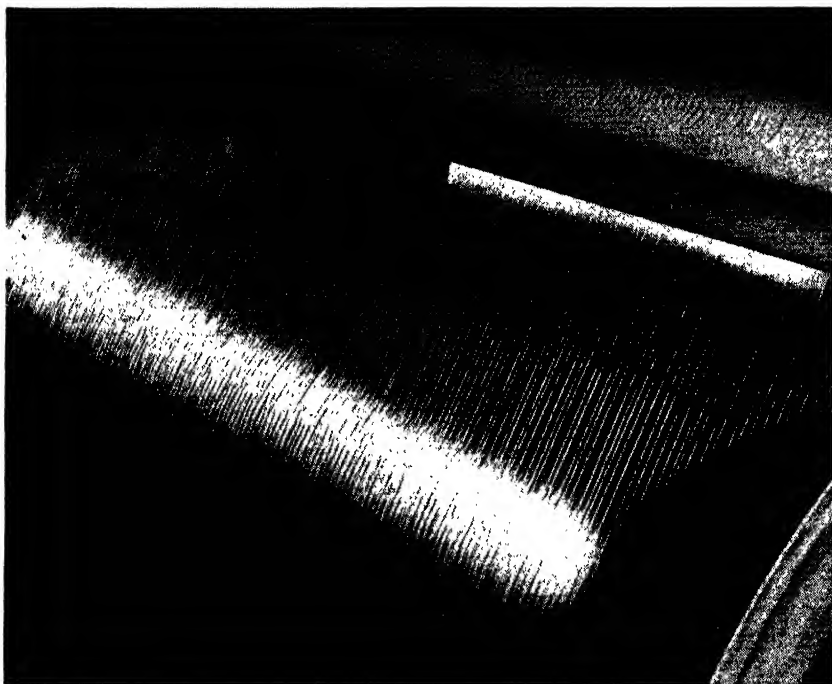
The rise of rayon staple fiber in recent years has been one of the outstanding developments in the whole field of textiles. Many in the trade believe that it will account for most of the rayon industry's expansion in the future. Here, too, the acetate, which is newer, has been growing at an even faster rate than viscose.

It is noteworthy that the price of viscose staple fiber has been steadily reduced until it is on a competitive basis with cotton. A manufactured fiber has been brought down in price to the level of the cheapest natural fiber!

In raw materials for rayon, the general tendency before the war was away from cotton linters to wood pulp.

NEW INDUSTRIAL USES OF RAYON

In the past, most rayon ordinarily has gone into style fabrics; that is, into fabrics where appearance is the decisive factor. Such uses were found principally in the field of clothing, particularly women's clothing, and household furnishings. Until



Courtesy American Viscose Corporation

FIG. 59. Here rayon tire yarn is being wound on to a beam for shipment to weavers of tire fabric.

recently, only small quantities of rayon were used for industrial purposes. The low strength of rayon and other characteristics prevented its widespread use in this field. The development of new high-strength types of rayon in recent years, however, has made possible its expansion into industrial applications. Of these, the most important has been for tire fabrics.

Tire Fabrics. Rayon tire fabrics were made experimentally as early as 1924, but were not utilized commercially until 1937, following the development of a suitable adhesive for bonding rubber to rayon and of a satisfactory high-strength rayon. For the first few years after its introduction, the use of rayon tire fabrics was limited almost entirely to high-speed, heavy-duty, truck and bus tires. Its superior durability under heavy service conditions, as compared with cotton fabrics, outweighed its higher price. In 1939 about 7 million lbs. of rayon yarn were used for this purpose, indicating the small market compared with approximately 288 million lbs. of cotton cord and fabric.

The war gave a tremendous impetus to the use of rayon for tire fabrics. This resulted from the decision of Government authorities to specify the use of high-tenacity rayon in tires for certain classes of military and civilian vehicles and aircraft. This decision was based on the fact that rayon tires give superior service under the conditions for which they were used and that less rubber is required to make them. It also was claimed that rayon tire fabrics were lighter and stronger than cotton fabrics and that they maintained their strength better under high temperatures. The latter was said to be important in view of the facts that more heat than usual is generated in military tires because of their extreme thickness, and that tires made of synthetic rubber give off more heat than those made of natural rubber.

Following this decision, a program was put into effect by the War Production Board providing for a vast increase in production of high-tenacity viscose-rayon yarn to a total of 240 million lbs. annually. The bulk of this was to be used in tires.

Although it generally is agreed that rayon tire fabric is superior to old types of cotton tire fabrics, there is considerable difference of opinion as to whether it is better for the various classes of service than the improved types of cotton fabrics which have been or are now being developed. Whether rayon will permanently displace cotton in tires will depend to a large extent on the relative prices of cotton and rayon fabrics, as well as on their

relative merits. One fact is clear—rayon is firmly entrenched in the tire cord field.

Another new industrial use of rayon is the application of rayon tow in mechanical packings.



Courtesy American Viscose Corporation

FIG. 60. Cross section of a heavy duty tire, showing rayon cords between layers of rubber. Rayon tire cord fabric in background.

CONSUMPTION OF RAYON AND OTHER FIBERS IN SPECIFIC USES

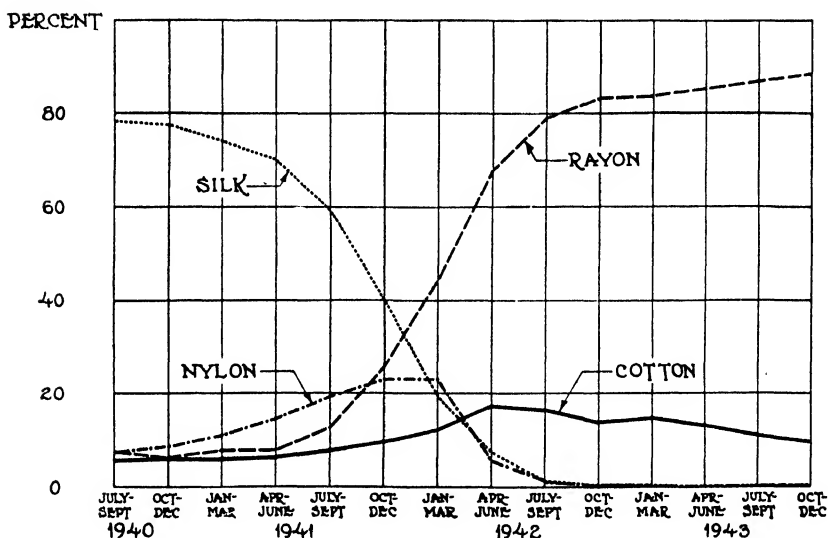
Woven Goods Other than Tire Fabrics. Woven goods, excluding tire fabrics, now use approximately three fourths of the domestic output of continuous filament rayon, most of the increase

having taken place within the last 10 years. Accurate data are not available in sufficient detail to trace the effects of competition of rayon upon the consumption of other textile fibers in woven goods, but the general effects are fairly well known. Silk has been directly and seriously affected, as indicated by estimates that its consumption in uses other than hosiery declined from 59 million lbs. in 1929 to 9 million lbs. in 1939. Had it not been for the increased use of silk in hosiery, the decline in total consumption of silk, prior to its withdrawal from use in 1941, would have been much more drastic. Cotton and wool also have been replaced by rayon, cotton probably being much more affected than wool.

Much of the competition between rayon and silk has been on the basis of price. The gain made by rayon is therefore likely to be permanent, since it is highly improbable that silk will ever be cheaper than rayon. On the other hand, much of the competition between rayon and cotton and between rayon and wool has been on the basis of fabric style characteristics. For example, rayon gained in the dress field at the expense of cotton not because of lower prices, but because of effective competition in appearance, draping qualities, and other style characteristics. The fact that the prices of cotton and wool rose markedly during the war while prices of rayon remained relatively stationary was, however, an important factor in the competition between these fibers.

Hosiery. Price, style, and serviceability are competitive factors that vary greatly in importance in determining relative quantities of the various textile fibers used in different types of hosiery. For example, in women's hosiery, appearance outweighs a considerable difference in price, and, beyond a certain required minimum, serviceability without satisfactory appearance is of little importance. In men's hosiery, price, appearance, and durability are of more nearly equal importance; whereas in children's hose, durability and price are of more importance than in either men's or women's hosiery.

In women's hosiery, extreme shifts have occurred in the relative use of textile fibers. In 1919, more than half of the women's hosiery produced was all cotton, but since then cotton has steadily declined in importance until less than 10% was all cotton in the years immediately preceding the war. In contrast, silk hosiery increased from 39% of the total production in 1919 to 84% in 1937 and 1939.



Courtesy Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration

FIG. 61. Shifts in percentages of women's full-length hosiery made of various fibers, United States, 1940-1943. Production of women's rayon hosiery (full-fashioned and seamless) increased rapidly after withdrawal of silk in August, 1941, and nylon in February, 1942.

Commercial introduction of women's nylon hosiery in May 1940 was followed by rapid consumer acceptance, and by the first quarter of 1941 this type accounted for 10% of the total production of women's full-length hosiery, including both full-fashioned and seamless.

Production of women's rayon hosiery (mostly made with cotton tops, heels, and toes) increased steadily from 2% of the

total in 1919 to 18% in 1929, but then declined to less than 10% in the years immediately preceding the war. A major factor in the trend since 1929 was a tendency toward use of sheer hosiery, for which rayon was not so suitable as silk, attributable largely to style changes affecting the length of women's dresses. Another factor was the steady decline in silk prices, which prevented rayon hosiery from making further gains after 1929.

During the war, however, rayon again gained rapidly in importance because of the lack of silk and nylon. A Government order in August 1941 prohibiting the use of silk for non-defense purposes necessitated greater use of nylon, rayon, and cotton. However, nylon, after gaining 23% of the women's full-length hosiery market at the close of 1941, was also withdrawn from civilian use in February 1942. In the meantime, rayon steadily increased in importance as the best available substitute for silk and nylon, and at the close of 1942 accounted for more than 80% of all the women's full-length hosiery manufactured. Use of cotton hosiery also increased somewhat, but did not rise to more than 10% of the total by the end of 1943.

Although considerable progress has been made since 1941 in adapting rayon for use in women's hosiery, the great majority of women still regard rayon as definitely inferior to both nylon and silk for this purpose. But further improvement in women's rayon hosiery is to be expected as the result of the use of high-tenacity rayon. It may result in new competition for nylon and silk in the hosiery market.

There were only small increases in the use of rayon for making half hose (principally men's), after 1929. This market took most of the rayon used in hosiery prior to the war. Cotton was the fiber most affected by competition from rayon in this use. However, cotton recovered substantially after 1929, and production of all-cotton hosiery for men and children rose from 42% of the total in 1929 to 55% in 1939. The greater use of cotton in this field was largely attributable to popularization of sport hosiery, such as anklets and slack and crew socks, which are made primarily of cotton.

Knit Goods Other than Hosiery. Data are not available showing the relative consumption of the various textile fibers in knit goods other than hosiery (principally knit underwear and outerwear). Cotton is by far the most important fiber used in these goods as a group, but rayon and wool are important competi-



Courtesy Tennessee Eastman Corporation

FIG. 62. Continuous filament acetate rayon yarn is wound on cones, ready for shipment to textile mills for weaving or knitting into fabrics.

tors. Consumption of rayon in knit goods other than hosiery has increased slowly in recent years.

CONSUMPTION OF RAYON BY TRADES

From 1912 to 1922, the greater part of the rayon produced went to the knit-goods trade, where most of it was used in hosiery.

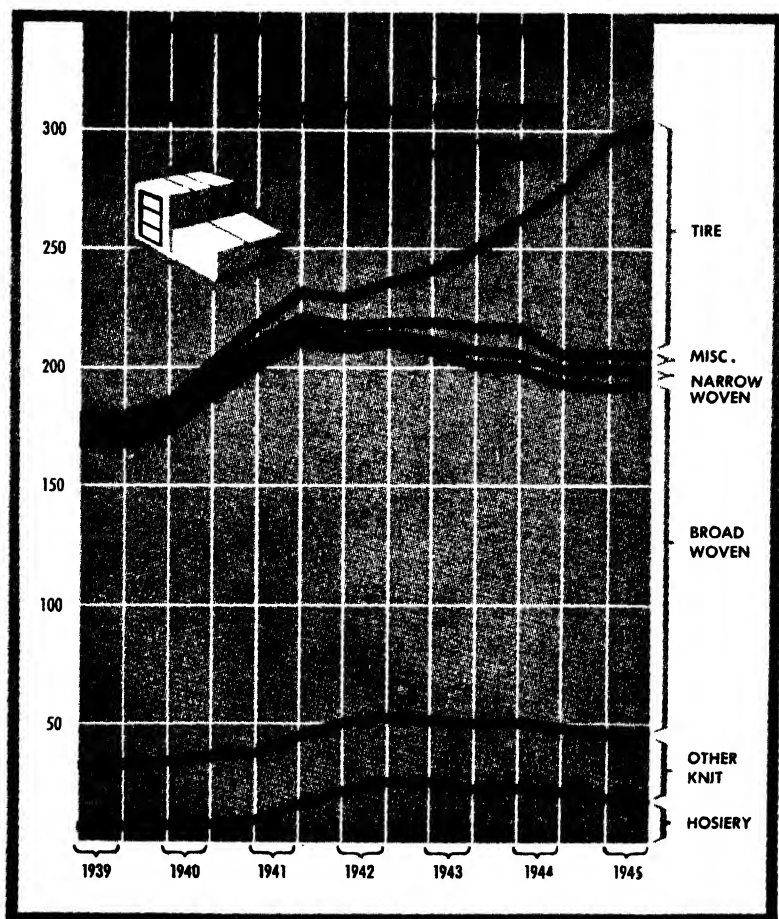
Beginning about 1923, and continuing through 1930, shipments of continuous filament rayon were about evenly divided, between the knit-goods and the woven-goods industries. By far the greater part of the rayon that went into knit goods was used to make underwear, dresses, sweaters, ties, and other items, while only a minor portion was used to make hosiery. In the woven-goods industry, broad goods took steadily increasing quantities, whereas narrow goods showed no appreciable rise on a poundage basis and declined as a proportion of the total.

During the period from 1930 to 1943, the use of continuous filament rayon increased more than fourfold. One outstanding feature of this growth in the use of filament rayon was that it occurred mostly in the woven-goods industry. The tremendous increase since 1930—more than 300 million lbs.—was almost entirely accounted for in woven goods. In contrast, consumption of rayon yarn in knit goods was only about 50 million lbs. greater and of this, 35 million lbs. represented a wartime increase in hosiery since 1940.

Consumption of Rayon Staple Fiber. Far more rapid than the growth of continuous filament rayon has been that of staple fiber. Before 1928, virtually no staple fiber was used in this country. As late as 1934, it showed no marked signs of becoming of much importance, but thereafter expansion was rapid. Consumption of staple fiber in 1935 accounted for little more than 2% of the total domestic consumption of rayon, by 1937 it had risen to nearly 12% and by 1944 to nearly 25%.

Data showing the consumption of staple fiber by individual products are not available, so that a discussion of its uses must be of a general nature.

By far the most important use for staple fiber is in woven goods, either unblended or blended with cotton or wool. It can be produced in any desired length and therefore can be converted into yarn on all types of cotton and wool spinning machinery. However, the bulk of the staple fiber is processed on cotton machinery.



Courtesy Rayon Organon

FIG. 53

Woven fabrics made of staple fiber have found their principal use thus far in women's and men's outerwear. One group of fabrics is made of staple fiber mixed with wool to simulate woolen and worsted fabrics such as flannels, tweeds, and twills, for use in men's and women's suits. In such applications, staple fiber may serve to lower the cost of the final product or to extend supplies of wool. Another group of fabrics in which staple fiber is used, including poplins, gabardines, and failles, either all rayon or mixed with cotton, find application in slack suits and sport shirts. Staple fiber also has a large market in women's dress goods, such as linen-like and challis-like fabrics, and washable shantungs.

Little use has yet been made of staple fiber in knit goods, except in small quantities for such applications as women's knit outerwear, underwear, and gloves, as well as men's hose. Staple fiber accounts for only a small percentage of the total fiber used for these products, and they in turn take less than 3% of all the staple fiber produced.

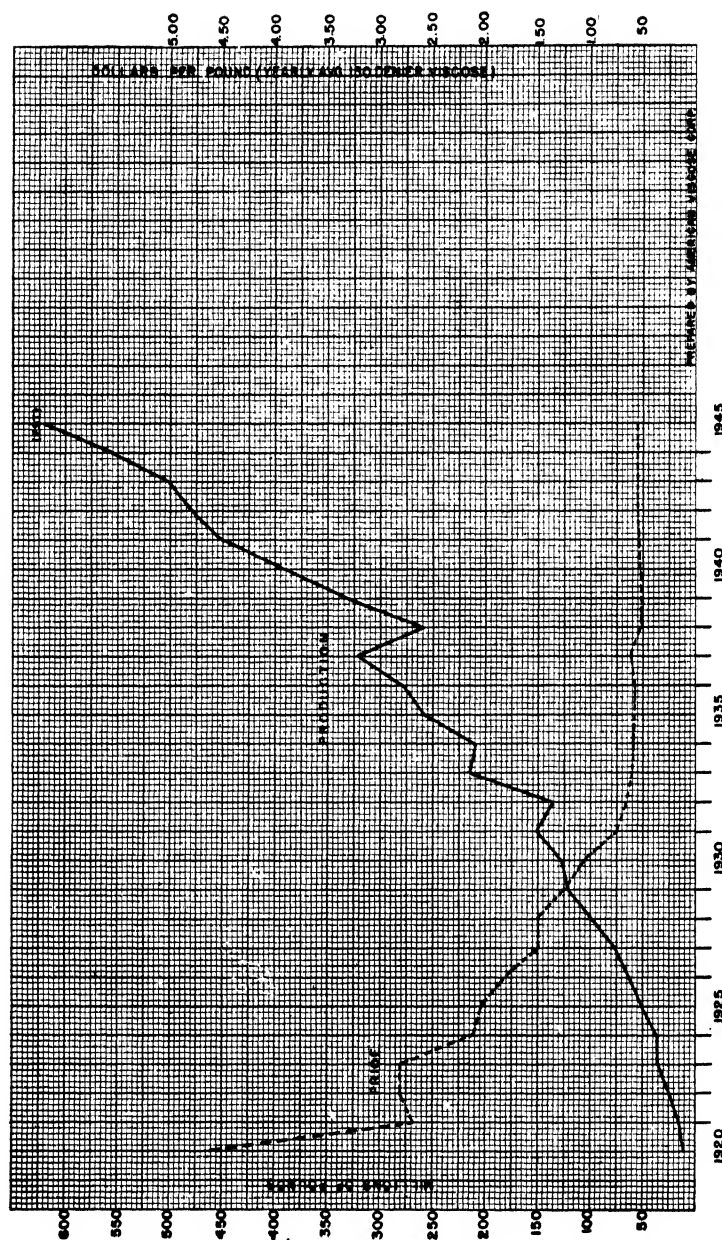
In non-apparel goods, staple fiber is used to a considerable extent in tablecloths, napkins, draperies, upholstery fabrics, etc. During the war it found increased use in wool mixtures for blankets and carpets.

Utilization of staple fiber is still in the development stage, and new uses are appearing as improvements are made in its physical characteristics and adaptability.

RELATIVE GROWTH OF THREE RAYON PROCESSES

Continuous Filament. Of the three types of continuous filament rayon produced in the United States, the acetate type has increased at a much faster rate in recent years than the other two. It rose from about 1% of the total in 1920 to 8% in 1930 and 34% in 1940, but declined to 31% in 1944. Output of viscose yarn, although substantially greater today on a poundage basis than in any prewar year, constitutes a smaller proportion of the total than it did previously. This is almost entirely the result of the much more rapid increase in production of acetate

RAYON YARN PRODUCTION U. S. INDUSTRY, 1920-1945



Courtesy American Viscose Corporation

Fig. 64. Rayon yarn production and price, 1920-1945. These curves typify the growth of the rayon industry. As production has risen, the price of rayon yarn has been reduced.

rayon yarn. Less than 5% of total rayon output is made by the cuprammonium process.

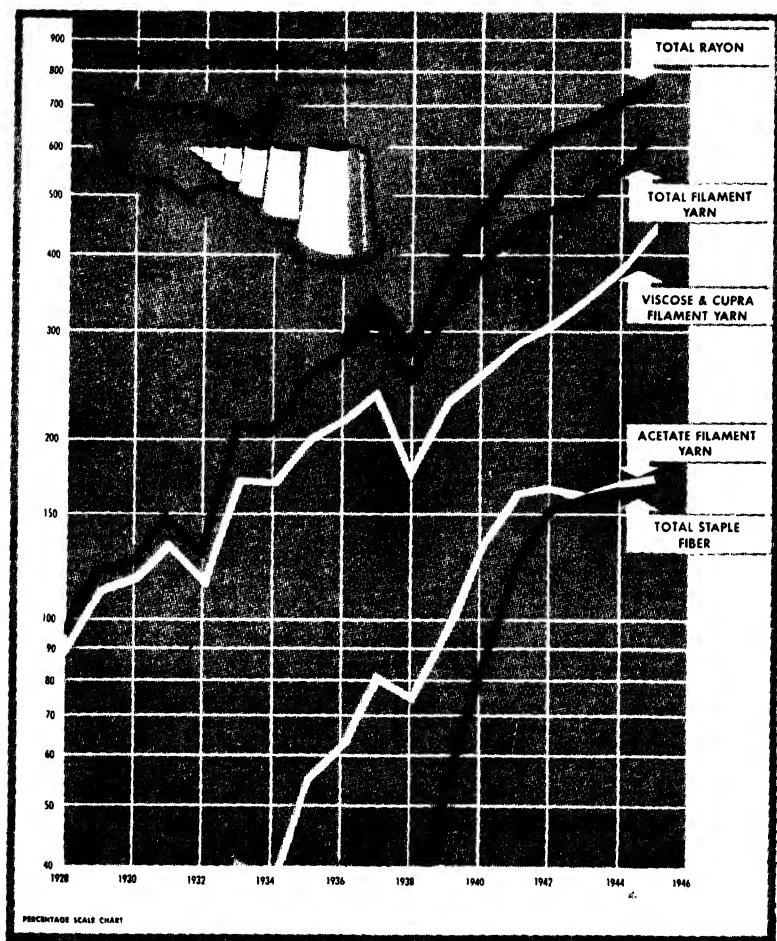
Staple Fiber. Production of staple fiber has shown extremely rapid growth since it came on the market in 1928. It now accounts for over 20% of total rayon output.

Until recently, separate production data were not reported for acetate and viscose staple fiber but such information is now available for a period of years. Production of viscose staple fiber increased from 0.2 million lbs. in 1928 to 129.1 million lbs. in 1945. Acetate staple fiber rose from 0.3 million lbs. in 1935 to 39.3 million lbs. in 1945. It will be seen that the growth of acetate staple fiber has been even more rapid than that of the viscose staple. The acetate staple now accounts for nearly 25% of total staple fiber production.

TABLE 14.1. U. S. PRODUCTION OF CONTINUOUS FILAMENT RAYON
MADE BY VARIOUS PROCESSES*

Year	Per cent		
	<i>Viscose and Cuprammonium</i>	<i>Acetate</i>	<i>Nitrocellulose</i>
1945	72	28	....
1944	69	31	....
1943	68	32	....
1942	65	35	....
1941	64	36	....
1940	66	34	....
1939	70	30	....
1938	70	30	....
1937	74	26	....
1936	77	23	....
1935	78	22	....
1934	80	18	2
1933	78	19	3
1932	81	14	5
1931	86	10	4
1930	88	8	4
1929	67	7	6

* Source: *Bulletin AIC-64*, Southern Regional Research Laboratory, U. S. Dept. of Agriculture.



Courtesy Rayon Organon

FIG. 65

RAYON PRODUCERS

The producers of viscose rayon, in approximate order of size, are: American Viscose Corporation, E. I. du Pont de Nemours & Co., Inc., Industrial Rayon Corporation, North American Rayon Corporation, American Enka Corporation, Celanese Corporation of America, New Bedford Rayon Company, Skenandoa Rayon Corporation, Hartford Rayon Corporation, Delaware Rayon Company, Synthetic Yarns, Inc., and National Rayon Corporation.

About 90% of all the viscose staple produced is made by American Viscose Corporation. E. I. du Pont de Nemours & Co., Inc., also is a manufacturer of viscose staple.

The producers of acetate rayon, in approximate order of size, are: Celanese Corporation of America, Tennessee Eastman Corporation (a subsidiary of Eastman Kodak Company), E. I. du Pont de Nemours & Co., Inc., and American Viscose Corporation.

About 70% of the acetate rayon staple produced is made by Tennessee Eastman Corporation. Other manufacturers of the acetate staple are Celanese Corporation of America, E. I. du Pont de Nemours & Co., Inc., and American Viscose Corporation.

The leading producer of cuprammonium rayon is American Bemberg Corporation. United States Rayon Corporation also makes cuprammonium rayon.

RAW MATERIALS FOR RAYON

The cellulose used by the rayon industry is derived from special types of wood pulp and certain grades of cotton linters. A number of considerations are involved in the rayon manufacturer's choice between wood pulp and cotton linters pulp, the chief ones being the physical and chemical properties of the pulp, its usable cellulose content, and the cost of processing it into rayon. The relative importance of these factors varies with the different processes.

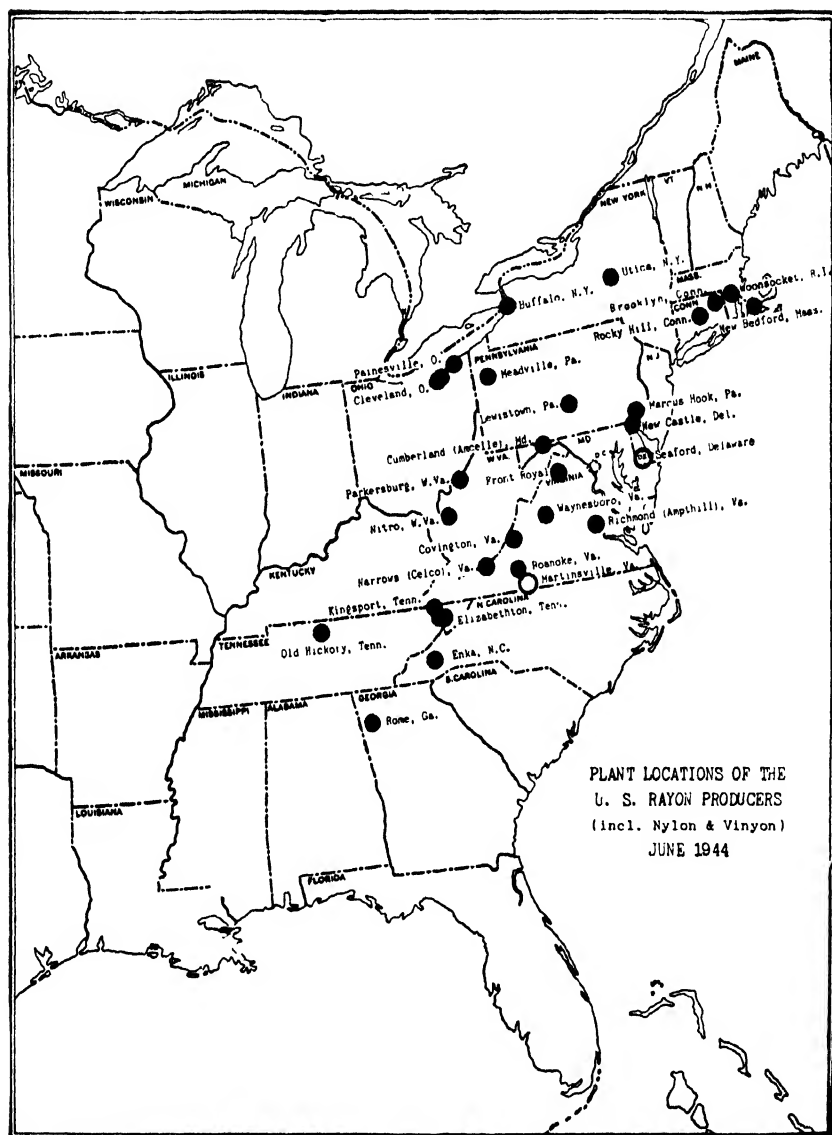
TABLE 14.2. RAYON PRODUCTION CAPACITY BY COMPANY
AS OF 1942*

VISCOSE PROCESS					
Company	Filament yarn (mil- lions of lbs.)	% of total	Staple fiber (mil- lion of lbs.)	% of total	Total filament yarn and staple fiber (mil- lion of lbs.)
American Viscose Corp.	100	33.3	105	90.5	205
E. I. du Pont de Nemours & Co..	68	22.7	11	9.5	79
Delaware Rayon Co.	3	1.0	...	...	3
Tubize Rayon Corp.†	16	5.3	...	...	16
Industrial Rayon Corp.	38	12.7	...	...	38
North American Rayon Corp. ...	30	10.0	...	...	30
American Enka Corp.	30	10.0	...	...	30
Hartford Rayon Corp.	4	1.3	...	...	4
New Bedford Rayon Co.	5	1.7	...	...	5
Skenandoa Rayon Corp.	5	1.7	...	...	5
Woonsocket Rayon Corp.†	1	0.3	...	...	1
Total	300	100.0	116	100.0	416
ACETATE PROCESS					
Celanese Corp. of America	80	19.1	5.0	25.0	85
Tennessee Eastman Corp.	34	20.8	14.0	70.0	48
E. I. du Pont de Nemours & Co..	25	15.3	0.7	3.5	26
American Viscose Corp.	20	12.3	0.3	1.5	20
Tubize Rayon Corp.†	4	2.5	...	...	4
Total	163	100.0	20.0	100.0	183
CUPRAMMONIUM PROCESS					
American Bemberg Corp.	14	93.3	...	...	14
Imperial Rayon Corp.	1	6.7	...	...	1
Total	15	100.0	...	...	15

* Source: "Maximum Price Regulation, 167—Rayon Yarn & Staple Fiber," Office of Price Administration, June 22, 1942.

† Manville Jenckes Corp., Woonsocket Rayon Div. (now Synthetic Yarns, Inc.).

‡ Acquired (1946) by Celanese Corp. of America.



Courtesy Rayon Organon

FIG. 66

The total consumption of wood pulp and linters pulp in rayon manufacture was more than five times as great in 1945 as in 1929 and more than doubled in the last 6 years. Cotton linters have accounted for a declining proportion of this total, although the trend has not been steadily downward. In 1929, linters pulp accounted for 36% of the total; in 1933, 43%; from 1937 to 1941, about 25%; and in 1942, 12%. Despite its declining relative importance, more linters pulp was used in 1941 than during any previous year, and consumption during the war rose to a new high level. The use of wood pulp increased at an even faster rate.

TABLE 14.3. CELLULOSE CONSUMPTION BY THE U. S. RAYON INDUSTRY*

Year	(Thousands of tons of refined cellulose)			Equivalent raw cotton linters (thousands of bales) ‡
	Total pulp	Wood pulp†	Linters pulp†	
1945	400	297	103	438
1944	367	285	82	350
1943	337	281	56	237
1942	320	280	40	168
1941	287	214	73	312
1940	238	178	60	256
1939	195	145	50	211
1938	148	110	38	160
1937	176	132	44	187
1936	151	104	47	201
1935	137	86	51	218
1934	112	63	49	209
1933	115	65	50	213
1932	74	43	31	132
1931	84	53	31	132
1930	72	45	27	115
1929	69	44	25	107

* Source: *Rayon Organon*.

† Wood and linters in purified form as used by rayon producers.

‡ Bales of raw cotton linters figured on the basis of one-third overweight on refined linters pulp (due to refining losses) and converted to bales on the basis of 625 lbs. net weight per bale.

TABLE 14.4. APPROXIMATE PROPORTION OF WOOD PULP AND
LINTERS PULP USED IN MAKING RAYON BY VARIOUS
PROCESSES IN U. S.*
(Per Cent)

<i>Year</i>	<i>Linters pulp</i>	<i>Wood pulp</i>	<i>Year</i>	<i>Linters pulp</i>	<i>Wood pulp</i>
1945	26	74	1936	31	69
1944	22	78	1935	37	63
1943	16	84	1934	44	56
1942	12	88	1933	43	57
1941	25	75	1932	42	58
1940	25	75	1931	37	63
1939	25	75	1930	38	62
1938	25	75	1929	36	64
1937	25	75			

* Source: *Rayon Organon*.

Viscose Rayon. In recent years there has been a strong incentive to use wood pulp instead of cotton linters to make viscose rayon, because the price of the pulp is usually lower and more stable. Moreover, the quality of wood pulp has been improved to such an extent that it is no longer necessary to use linters pulp to make viscose rayon of standard quality. However, linters pulp has a usable cellulose content of about 98%, as compared with only about 92% in the grade of wood pulp generally used for viscose rayon. Therefore, the difference in net costs to the manufacturer is not quite so great as indicated by a comparison of these sources of cellulose on a per ton basis. Nevertheless, wood pulp is usually the cheaper of the two for making rayon by the viscose process.

In the earlier years, following the first use of linters pulp in the production of viscose rayon, most manufacturers held the opinion that a better quality of rayon could be made with a mixture of linters and wood pulp than with 100% wood pulp. In 1929, about 30% of the total pulp used in the production of viscose rayon was linters pulp, certain manufacturers using a higher percentage and others a lower. By about 1932, it was

found possible to use increasingly higher percentages of wood pulp in the viscose process, as a result of improvements in its quality. A few years later most viscose producers were using wood pulp exclusively.

However, cotton linters are still used to some extent in the viscose process. They are regarded by some manufacturers as necessary in the production of certain types of high-strength viscose yarns, which have increased steadily in importance since they were first introduced in 1937. Certain manufacturers use only cotton linters in making high-strength viscose rayon; others use mixtures of linters and wood pulp, and at least one producer uses wood pulp exclusively.

Acetate Rayon. Prior to 1940, only cotton linters were used in making acetate rayon in the United States. With the continued expansion of acetate rayon production, the point was reached after 1936 where this process took the major part of the linters pulp used in the rayon industry. In 1929, the acetate process consumed approximately one eighth of all the linters pulp used in making rayon, but by 1933 this proportion had increased to one fourth and by 1937 to about two thirds of the total.

Experiments aimed at the commercial utilization of wood pulp for making acetate rayon were unsuccessful for many years but eventually resulted in a highly purified grade of wood pulp having an available cellulose content nearly equal to that of linters. This type of wood pulp is now being used on a large scale for making acetate rayon. Its price is about \$25 per ton higher than that of the wood pulp generally used for viscose rayon, but considerably lower than that of linters pulp.

Cuprammonium Rayon. Until about 1939, no wood pulp had been used for the cuprammonium process in the United States, except on a small experimental scale. Highly purified

wood pulp, however, has been used for this purpose in recent years. Cuprammonium rayon has constituted less than 5% of the total rayon produced and therefore has not had an important effect on trends for the industry as a whole.



Courtesy Tennessee Eastman Corporation

FIG. 67. Cotton linters are taken from the cotton seed after the spinnable cotton has been ginned. The short, fuzzy fibers are bleached and scoured to a fluffy mass of pure cellulose.

RAYON PRICE TRENDS

Continuous Filament Rayon. The price of continuous filament rayon has undergone a gradual decline over a period of years, as productive output attained larger volume, manufacturing technique improved, and competition became keener. This

is illustrated by the price history from 1911 to 1945 of 150-denier viscose-rayon yarn made in the United States. There was a temporary rise during World War I, followed by unusually high prices during the years immediately after the war. But subsequent to this, there was a marked downward trend, lasting from 1920 to about 1934. Since 1934, there has been little further decline in the price of rayon, which remained relatively stable during the last war despite large increases in the general price level.

Although corresponding data for other countries are not available for comparable periods, there was a decided decrease in rayon prices throughout the world during the period between World War I and World War II.

Prices of cotton and wool yarns also fell in the 10-year period ending in 1932, but their decline was not nearly so marked as in the case of rayon. Moreover, prices of wool and cotton yarns have advanced considerably since 1932, whereas rayon prices have fallen further. Even though price is not the determining factor in many uses where rayon competes with cotton and wool, the continued decline in the price of rayon compared with the prices of the other fibers has undoubtedly strengthened its competitive position.

The price of silk had dropped about as rapidly and in nearly the same proportion as the price of rayon during the 15 years preceding World War II. Although this decline was caused by a number of factors, a large part of it was directly attributable to the effects of competition from rayon. To some extent, the price of rayon kept the price of silk from rising above a certain relative level. If silk went beyond that level, large quantities of it were rapidly displaced by rayon, especially in woven goods. The price of silk, however, in spite of such competition, remained several times that of rayon.

Staple Fiber Rayon. Prices of both types of staple fiber have declined considerably since their introduction, each change, until very recently, having been a reduction. This is indicated in

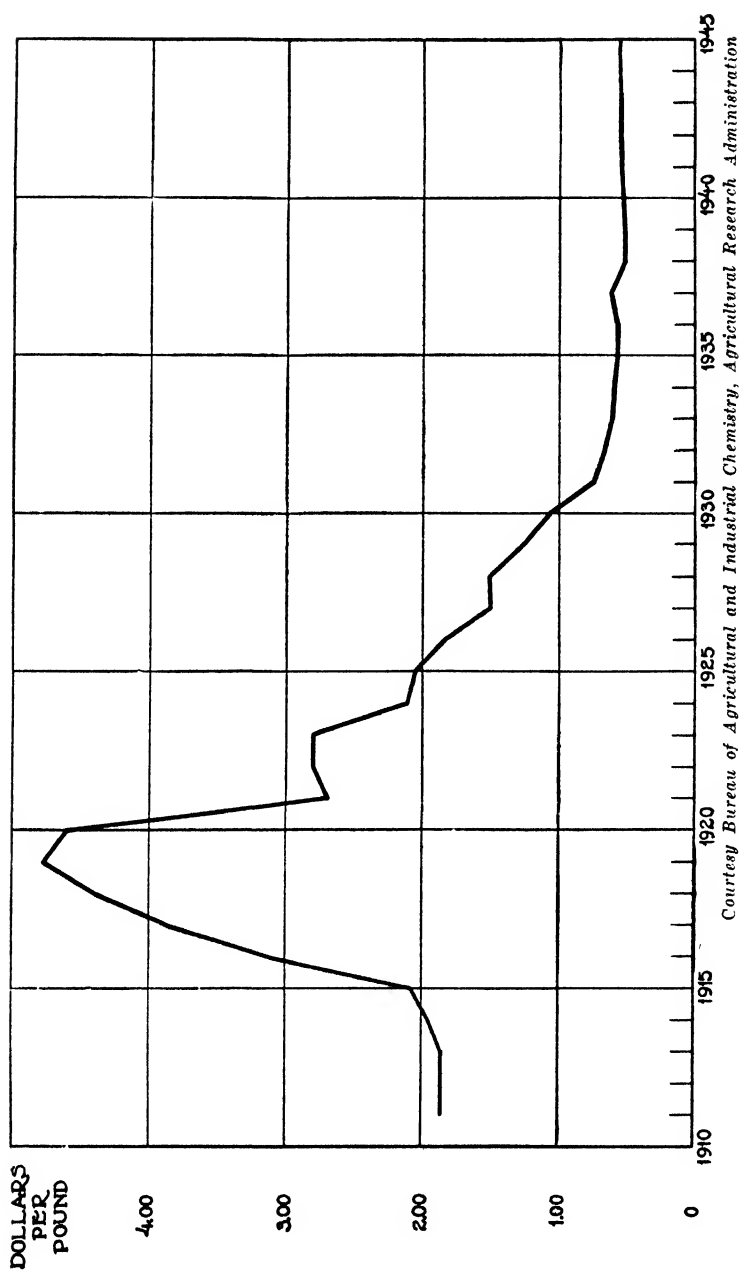


FIG. 68. Average yearly price per pound of 150 denier continuous filament rayon yarn, 1911-1945. The price of rayon rose sharply during and immediately after World War I but has since declined and is now less than a third of the price before that period.

Courtesy Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration

the accompanying table which shows the prices of viscose and acetate rayon staple fiber since the approximate beginning of commercial production in the United States.

The price margin between rayon staple fiber and cotton has narrowed considerably since 1928. In 1943 and 1944, viscose rayon staple fiber cost less than 4¢ per pound more than middling, 15/16-inch cotton. Viscose rayon staple fiber has been selling for less than one fourth the price of scoured fine territory wools since 1940. Viscose staple is the cheapest of all manufactured fibers.

TABLE 14.5. PRICES PER POUND OF RAYON STAPLE FIBER*

<i>Viscose</i>		<i>Acetate</i>	
<i>Effective date of price change</i>	<i>New price (cents)</i>	<i>Effective date of price change</i>	<i>New price (cents)</i>
1944, March	25	1944, October	38
1943, May	24	1940, January	43
1937, September	25	1938, January	46
1936, June	28	1937, February	52
1934, February	34	1936, November	54
1932, August	40	1936, July	60
1931, October	50	1936, March	80
1928, January	60		

* Source: *Rayon Organon* and Southern Regional Research Laboratory, United States Dept. of Agriculture.

EFFECTS ON THE CONSUMPTION OF COTTON, WOOL AND SILK

Consumption of silk, the textile fiber first to be affected by the competition of rayon, increased until 1929 but thereafter underwent a continued decline, which lasted until its withdrawal from commercial use in 1941. The decline in the use of silk in the early 1930's was attributable largely to a fall in consumer purchasing power during the depression, as silk is a luxury item and therefore very sensitive to changes in economic conditions. But the failure of silk to recover its former markets after 1934, when purchasing power was rising, in spite of its

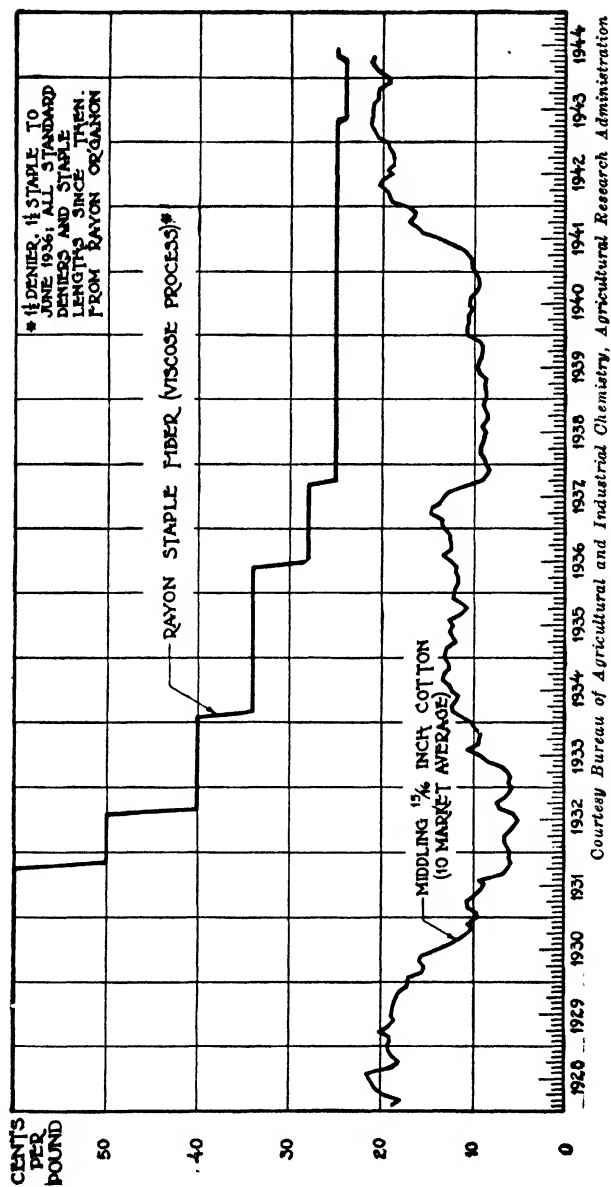


FIG. 69. Price per pound of cotton and of rayon staple fiber.

greatly reduced price, was almost wholly the result of competition from rayon.

Trends in the consumption of wool have revealed no declines that may be ascribed to the competition of rayon. Consumption of wool showed a fairly level trend from 1918 to 1940, if allowance is made for the depression of the 1930's. Since 1940, it has risen to record levels in response to wartime military needs. Nevertheless, rayon is being used in increasing quantities for many of the same purposes as wool, in the form both of all-rayon fabrics and fabrics made of wool and rayon blends. An important factor in this competition has been the development of rayon staple fiber, because the appearance and certain other characteristics of wool fabrics can be simulated more closely with staple fiber than with continuous filament rayon. Since the quality and versatility of staple fiber are being improved steadily, further increases in its use as a substitute for wool are likely.

For many years after its introduction, rayon was not generally considered a competitor of cotton. It is now widely recognized, however, that a considerable part of the expansion in consumption of rayon has been at the expense of cotton. The consumption of cotton is, of course, affected by so many different factors that it is not possible to calculate with accuracy the actual poundage lost to rayon, but part of the downward trend can be attributed directly to displacement by rayon. Even though the proportion of cotton to the total consumption of all fibers has declined slightly over the past decade, it still has no competitor in the textile field that even approaches it in importance.

EXPORT MARKETS FOR RAYON

Before the war an impressive quantity of filament rayon yarn was imported into countries throughout the world which did not have their own rayon industries. It may surprise the reader to learn that such areas as the Dutch East Indies, the Philippines, Africa, the Near, Middle and Far East imported in excess of

150 million lbs. of rayon yarn annually, generally woven into low price piece goods by domestic weaving mills. India alone imported 60 million lbs., and China about half that quantity of rayon yarn annually.

During the war, most of those countries were cut off from all imports of rayon yarn and the resulting shortages helped to create a demand for home industries which would not be dependent upon imports. Furthermore, in some of the countries considerable capital was accumulated during the war for which suitable investments were needed.

This trend is borne out by the recent establishment of rayon plants in Peru, Brazil, Egypt and India, all built during 1944 and 1945.

As a result of the establishment of rayon plants in countries which formerly relied on imports, the export markets of the established producers may be reduced. It is believed that this trend will continue. American rayon producers are in a relatively fortunate position inasmuch as they have always relied almost entirely on the domestic market. The limited amount of rayon yarn allocated to foreign countries by the United States during the war was not nearly sufficient to satisfy their demand. As the world shortage will probably continue for a number of years, many additional rayon plants may be expected to be built in Asia, Africa and South America.

In general, preference is given to the viscose process since it has proved the most economical and suitable for the needs of countries which do not have a textile industry so highly developed as that of the United States, nor the high wage scale prevailing in this country.

A considerable number of plants which were destroyed during the war will have to be rebuilt and no doubt these plants will be equipped with the latest machinery and processes. These developments will help make most countries independent of rayon imports, but should result in considerable business for the textile machinery industry in this country for the next 5 or 10 years.

REFERENCES

1. *Rayon Organon*, published by Textile Economics Bureau, Inc., New York.
2. "Survey of Development and Use of Rayon and Other Synthetic Fibers," R. B. Evans, Southern Regional Research Laboratory, U. S. Dept. of Agriculture, New Orleans, La., October 1944.



Courtesy Celanese Corporation of America

FIG. 70. Fortisan is well adapted for use in applications ranging from shroud lines for parachutes to sheer fabrics for wearing apparel.

CHAPTER XV

New Cellulosic Fibers

SUMMARY

Some entirely new types of cellulosic fibers have been developed within the past decade, particularly during the war. One of these is Fortisan, made by saponifying cellulose acetate. It ranks among the strongest of all textile fibers. Fortisan had a number of interesting war uses which foreshadow peacetime applications where combined high strength and dimensional stability are required.

Other new commercial cellulosic products of possible interest to the textile industry are cellulose acetate butyrate monofilaments and Bubblfil.

The possibilities of ethyl cellulose, methyl cellulose, cellulose formate, and cellulose butyrate as fiber-forming materials also are discussed in this chapter.

FORTISAN

History and Development. "Fortisan" is the registered trade name for an ultra strong yarn developed by Celanese Corporation. It is made by subjecting a suitable cellulose acetate yarn to mechanical treatment to obtain a parallel molecular structure, then to saponification. This yields a regenerated cellulose yarn, which is chemically similar to cotton.

Fortisan was produced in small quantities before the war by British Celanese Limited. Although it had been under development for about ten years prior to the war, it had its real begin-

ning during the war. Its first military use was in parachutes when normal British supplies of linen were cut off from Belgium.

In the United States, Fortisan was produced in a small pilot plant by Celanese Corporation of America in 1941. Here, too, the war resulted in rapidly increasing production. It is estimated that from 20 to 30 million square yards of Fortisan (weighing 0.8 ounce per square yard) were used, principally to make flare parachutes.

During the war, the entire domestic output of Fortisan, of the order of 1 million lbs. a year, went into military applications. In addition to various types of parachutes, the applications included light, high-strength coated fabrics; webbings; tapes; sewing threads; shroud lines; core threads for tinsel conductors, and many others.

In most of these applications, a combination of extreme strength and lightness was required. Fortisan flare cloth had a breaking strength of nearly 50 lbs., which compared with about 26 lbs. for silk, the fabric previously used. Moreover, Fortisan flare cloth could be packed into a very small space.

Another war application of Fortisan was in balloon valve cords. Such cords must maintain a constant length even when saturated with moisture and a material having good dimensional stability was required. The expansion and contraction of Fortisan during wetting out and drying are so small as to be practically negligible. This also helps to explain its use in acoustical diaphragms.

Another development has involved the impregnation of Fortisan fabrics with various resins and their subsequent lamination, for the purpose of replacing metals in various structures. The resulting laminates have a low specific gravity and yet possess such high strength that the assemblies in which they are used remain rigid and hold their form without the necessity for internal bracing.

TABLE 15.1. PROPERTIES OF FORTISAN* †

Tenacity, dry	7.0 gms./denier
Tenacity, wet	6.0 gms./denier
Tensile strength	140,000 lbs./sq. in.
Elongation, wet or dry	6.0 to 6.5%
Modulus of elasticity, in tension	4.5×10^6 lbs./sq. in.
Specific gravity	1.50
Moisture regain	9.8% (dry basis)
Ironing temperature	20° C. higher than viscose rayon
Flammability	Flammable
Resistance to insects, bacteria, etc. ...	Same as cotton
Chemical resistance	Same as cotton

* Source: Celanese Corp. of America.

† 65% relative humidity at 70° F.

Properties. Among the outstanding physical properties of Fortisan are its extreme strength, dimensional stability, and resistance to stretch.

The yarn has undergone considerable improvements in strength and other characteristics since it was first introduced. This is indicated by the development of a special high-tenacity type:

	High-tenacity	Regular
Tenacity, dry (gms./denier)	7.0	5.6
Tenacity, wet (gms./denier)	6.0	4.0
Elongation, % wet or dry	6.0-6.5	6.0-6.5

Source: "Progress in Fortisan, the Strong Yarn," by W. Whitehead, *Rayon Textile Monthly*, September 1943, p. 58.

Note: Relative humidity 65% at 70° F.

The specific gravity of Fortisan is about 1.5. When allowance is made for its weight, Fortisan makes a much better showing in strength when compared with other fibers. Thus, while Fortisan has about the same tenacity as strong nylon, it has a much higher tensile strength. The tensile strength of Fortisan is about 140,000 lbs. per sq. in., which is considerably above

that of other textile fibers. Only certain types of glass fibers have a reported tensile strength higher than this.

Although Fortisan is not light in weight compared with most other fibers, for all practical purposes it might well be considered a "light" fiber. Because of its extreme strength, it can be used in smaller quantities to do the work that would require considerably larger quantities of fibers ranking lower in strength.

A general idea of the high strength of Fortisan may be realized by comparing it with metals.

	<i>Ultimate strength</i> (lbs./sq.in.)	<i>Specific gravity</i> (to 0.1)	<i>Strength ÷</i> <i>Specific gravity</i>
High-tenacity Fortisan . . .	138,000	1.5	92,000
Iron wire (unannealed) ..	60,000	7.5	8,000
Steel	80,000-330,000	7.7-7.9	10,100-42,300

Source: "Progress in Fortisan, the Strong Yarn," W. Whitehead, *Rayon Textile Monthly*, September 1943, p. 58.

According to a report of British Celanese, Ltd., Fortisan can be produced having a tenacity as high as 11 grams per denier, compared with 6 to 7 grams per denier previously. The yarn can be made as extensible as needed in practice for most textile purposes, at the expense of a certain amount of strength.

Fortisan has a high modulus of elasticity in tension (4.5 million lbs. per sq. in.). Its great resistance to stretch makes it especially suitable for use in sewing threads; as high as 6000 stitches per minute can be made without stretching the thread.

Fortisan has chemical properties very similar to those of other cellulosic fibers such as cotton or flax. Like other cellulosic fibers it is inflammable. It washes like cotton or linen. However, its ironing temperature is 20° C. (36° F.) higher than that of cotton or viscose rayon.

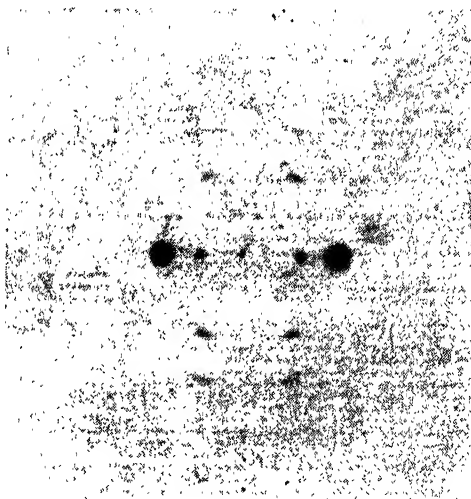
Dyeing. The following information on the dyeing of Fortisan has been contributed by W. Whitehead, Technical Dept., Celanese Corporation of America:

Fortisan as a cellulosic yarn dyes with colors normally employed on cotton or linen such as direct colors, sulfurs, naphthols, developed colors, vats, etc. Extremely fast dyeings are obtainable. The fineness of filament of Fortisan as currently made results in somewhat more dyestuff being required for the medium and dark shades than is commonly required on cotton, because of the greater surface/mass resulting from the fine filaments which results in greater light reflection and diffusion. Dyeing affinity rates are increased by pretreating Fortisan with cold aqueous alkali, such as 7% caustic soda at 68° F. (20° C.) for five minutes, then rinsing thoroughly. Temperature and concentration of alkali are critical but time is not as critical.

This treatment may be varied according to results required. The treatment lowers the breaking load moderately but increases the elongation. The treatment also improves resistance to abrasion either dry or wet such as wear and laundering, and improves sewability and seam strength in the case of Fortisan sewing threads. Treatment by padding or immersion is equally effective.

Types. Fortisan can be produced either as continuous filament or staple fiber. The staple fiber can be blended and spun on any standard textile system.

The possible range of deniers and deniers per filament is very wide. Typical yarns are 30, 40, 60, and 90 denier, and heavier



Courtesy Celanese Corporation of America

FIG. 71. X-ray spectrograph of Fortisan filaments.

deniers (e.g., 1100) are produced. Most of the yarn is 0.75 denier per filament. Thus, in the 30 denier yarn there are 40 filaments. Much finer deniers are made and filaments down to 0.1 and less have been produced.

For special electrical purposes a filament size of one eighth of one denier is used. This filament has a diameter of $1/10,000$ of an inch and 1 lb. of it would be 20,000 miles long. To make a 20 denier yarn, 160 filaments are twisted together.

Applications. Fortisan should find an important place in many fields where extreme strength, light weight and dimensional stability are required. For example, Fortisan fabrics suitably coated can be made into raincoats of high strength and of so little bulk that they will fit into a lady's handbag. The yarn can be woven into fabrics which are well suited for use in men's and women's underwear, as well as in slippers, foundation garments, and sheer dress fabrics.

Fortisan should also find a number of industrial uses; in the electrical trades, for heavy duty sewing threads, and as the textile component in high-pressure hose and plastics laminates.

TABLE 15.2. APPLICATIONS OF FORTISAN

War Applications

Numerous parachutes, ranging from flare to cargo types, and including shroud lines, etc.
Tinsel conductor core thread used in radio head sets and heated flying suits
Balloon fabrics and valve cords
Coated rainwear
Deacceleration suits (for Royal Canadian Air Force)
Sewing threads
Tapes
Resin laminates
Tow targets
Arctic ski tents (olive drab on one side and white on the other)
Filter cloths
Polishing cloths (for lenses)

TABLE 15.2.—*Continued**Civilian Applications*

Sheer dress goods
Corsets and foundation garments
Textile in two-way stretch garments
Satins and twills
Warp knit for underwear
Light coated rainwear
Fine shirtings
Sewing threads
Tapes and heavy cords
Fishing lines
Wind cords and other stretch resistant strong braids (e.g., for radios)
Tinsel conductor core threads (e.g., for electric shaver cords, heating pads and blankets)
Conveyor belts
Airplane wing fabric
Airship fabric
Parachutes
Crash-proof gasoline tanks
High-pressure hose
Sail cloth
Acoustical diaphragms
Camera bellows
Coated convertible automobile tops
Resin laminates
Outside surgical sutures
Surgical elastic bands
Bolting cloth for screen printing
Typewriter and cash register ribbons
Refrigerator bags
Dress shields
Dental floss

Production and Prices. Production of Fortisan is not very large, being of the order of 1 million lbs. a year, for 1944.

Introductory civilian prices for Fortisan were as follows:

<i>Denier Yarn</i>	<i>Per Pound</i>
30	\$3.00
40	2.95
60	2.90
90	2.80

Prices, as of July 1, 1946, were as follows:

<i>Denier Yarn</i>	<i>Per Pound</i>
30 and 40	\$2.85
50 and 60	2.80
75 and 80	2.75
90	2.70
150	2.60
270	2.40

CELLULOSE ACETATE BUTYRATE MONOFILAMENT

Cellulose plastics such as the acetate butyrate, which is marketed by Tennessee Eastman Corporation, under the trade name, Tenite II, can be extruded through small holes in the form of continuous monofilaments which have a smooth surface and a cross section which may be round, oval, or otherwise shaped according to the shape of the die. These monofilaments are made in white or any color which can be incorporated in the plastic mass before extrusion and they can also be made either transparent or opaque. They have been made in diameters ranging from 0.015 in. upward. They are used in woven and knitted accessories, such as handbags, shoes, etc., and also in upholstery.

BUBBLFIL

A novel material, known as "Bubblfil," was announced by E. I. du Pont de Nemours & Co., Inc., in 1942. It is of interest chiefly in that it represents a filament in which air is incorporated at intervals, making it look like a string of transparent beads.

Bubblfil is a form of regenerated cellulose made by the viscose process. The viscose material is extruded through a single spinneret hole, relatively large in size. A small amount of air is injected into it at regular intervals just as the filament is coagulated by the acid bath in which it is being spun.

The size and spacing of the bubbles, which are streamlined in shape, may be varied. Much of the bubble-strand had bubbles a little more than a quarter of an inch long, running three to the inch. A smaller size was also made.

Interest in Bubblfil during the war centered in its possibilities as a substitute for kapok. It was suggested for a variety of applications, including interlining and stuffing materials.

ETHYL CELLULOSE FIBER

Ethyl cellulose is one of the newer cellulose derivatives to assume commercial importance. Its chief outlets are in plastics and protective coatings.

Early attempts to produce fibers for textile applications were made with ethyl cellulose containing about 47.5% ethoxyl. This material has a low softening point and is affected by common dry-cleaning agents. More recent developments have made available ethyl cellulose with an ethoxyl content of 44.5% which is an improvement over the earlier higher-substitution product. Interesting fibers can be produced from this material.

While there has been no commercial development of ethyl cellulose fibers, their resistance to acids, alkalies, and washing compounds combined with good dyeing properties should be of interest for some textile applications.

TABLE 15.3. TYPICAL PROPERTIES OF ETHYL CELLULOSE FIBER*

Tenacity (dry)	.....1.3 to 1.5 gms./denier
Tenacity (wet)	.....0.95 to 1.1 gms./denier
Elongation (dry)	.....20 to 7%
Elongation (wet)	.....11 to 6%

* Data from laboratories of Hercules Powder Company.

The Dow Chemical Company has carried on research and development work on fibers made from ethyl cellulose (Ethocel fibers).

METHYL CELLULOSE FIBER

Methyl cellulose as supplied by industry is soluble in water and insoluble in all organic solvents. Aqueous solutions have a very rapid rise in viscosity with concentration and fibers would have to be spun from 5% solutions or less. Fibers so produced are water soluble and have no industrial development.

CELLULOSE FORMATE FIBER

Cellulose formate aroused considerable interest among experimenters shortly after its discovery in view of the fact that it was the only soluble organic ester of cellulose that could be prepared without the use of anhydrides. Concentrated formic acid was used with zinc chloride or hydrochloric acid as a catalyst. This interest was rather short lived due to the inherent instability of the cellulose formate. Tocco¹ described in considerable detail the preparation and properties of cellulose formate alone and admixed with proteins. When cellulose formate is allowed to stand wet, appreciable hydrolysis takes place. When it is dried at elevated temperatures, complete breakdown occurs and regenerated cellulose is obtained. This instability combined with the extreme corrosiveness of the reaction mixture has made it unsuitable for commercial development.

CELLULOSE BUTYRATE FIBER

Cellulose butyrate is prepared by reacting butyric anhydride with cellulose in the presence of a catalyst. Fibers prepared from cellulose butyrate are somewhat more extensible than cellulose acetate, and their low melting point renders them unsuited for general textile use.

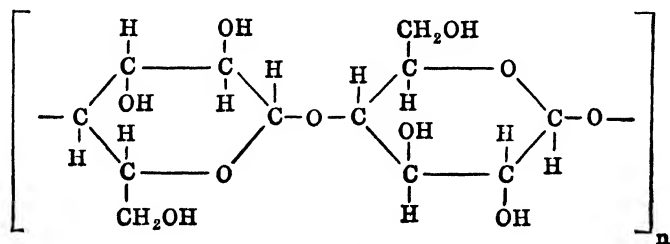
¹ G. Tocco; *Giorn. chim. ind. applicata*, Vol. 13, 1931, pp. 325, 414.

CHEMISTRY

The chemistry of cellulose is of great interest since most of the fibers used in our present-day civilization are based on cellulose. They include not only cotton, flax, ramie, and a number of other natural fibers, but also viscose, acetate and cuprammonium rayons. They also include some of the newer fibers such as saponified cellulose acetate (regenerated cellulose), ethyl cellulose, and others.

Cellulose is the main structural material of all plant life. It is a high molecular weight compound containing carbon, hydrogen, and oxygen, built up by the polymerization of numerous molecules of the simple sugar, glucose.

Cellulose can be defined as a linear polymer consisting of glucose anhydride units linked through the 1 and 4 carbon atoms by a beta-glucoside linkage. The number of glucose anhydride units per molecule varies within wide limits, but the average number per molecule for cotton cellulose is about 200. The probable molecular weight of cellulose lies between 20,000 and 40,000. The structural unit of the cellulose molecule can be illustrated by the following formula:



Cellulose

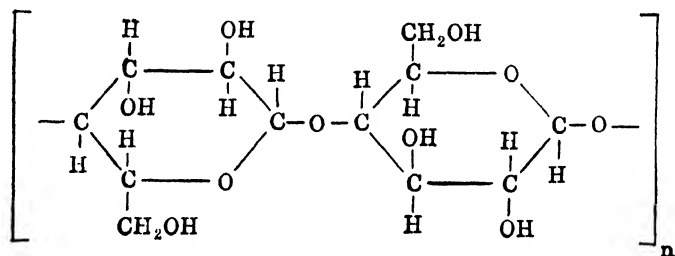
The cellulose content of raw cotton fiber ranges from 88 to 96% of the dry weight; whereas the scoured, bleached, dry cotton fabric is approximately 99% cellulose.

Ramie fiber, dried and cleaned, contains from 97 to nearly 99% pure cellulose. The extraordinary strength of ramie is related to the continuity of the cellulose crystals which are believed to lie parallel to the fiber axis. In the case of cotton, however,

the cellulose crystals are assumed to lie at an inclined angle to the fiber axis.

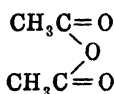
Viscose and cuprammonium rayons consist essentially of pure cellulose.

Cellulose Acetate. Cellulose acetate can be prepared by reacting cellulose with acetic anhydride in the presence of acetic acid, using a catalyst such as sulfuric acid. This can be shown by the following structural formulas:

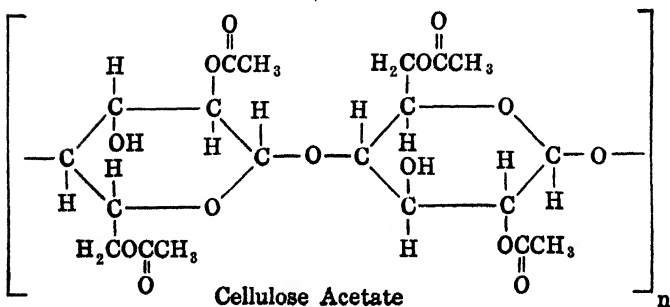


Cellulose

+



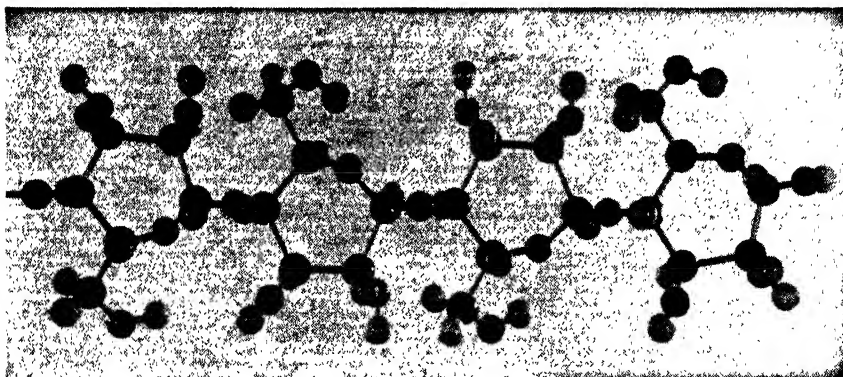
Acetic Anhydride



Cellulose Acetate

Cellulose acetate compounds vary considerably in their degree of acetylation and in their solubility in many common solvents. Since the smallest molecular aggregate of cellulose is known to contain many hundreds of units with six carbon atoms and three hydroxyl groups, it is evident that there can be unlimited degrees of acetylation.

Complete acetylation results in cellulose triacetate which is insoluble in most commercial low cost solvents. In order to utilize cellulose acetate, some of the acetate radical must be "knocked



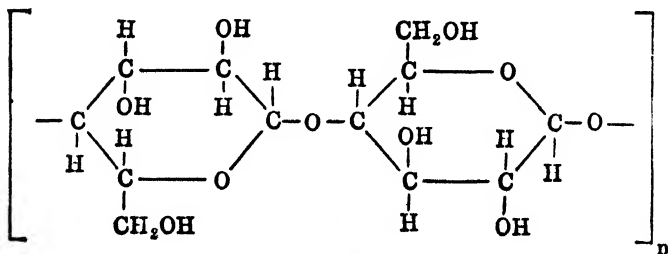
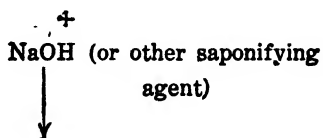
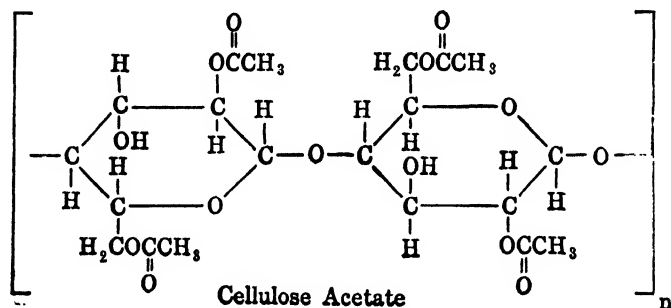
Courtesy Hercules Powder Co.

FIG. 71A. Space model of part of the cellulose molecule. Cellulose, which is the basis of most of the fibers in use today, has a very complicated chemical structure.

off" by a process of hydrolysis. This in turn opens the way for moisture absorption which reduces the dimensional stability and weathering characteristics of the material.

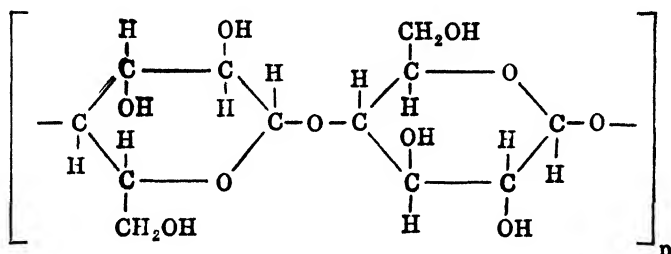
Cellulose acetate is available commercially for various uses in a range of compositions. The combined acetic acid component varies from 62% for the triacetate to as low as 52% in compositions used for plastics. The range found most suitable for yarn and staple fiber is 54 to 55%.

Saponified Cellulose Acetate. Fortisan is a regenerated cellulose yarn produced by highly orienting the internal filament structure of a cellulose ester yarn, for example cellulose acetate, then saponifying, i.e., splitting off the combined acid radicals. The process of orientation and saponification results in extremely high strength and resistance to stretch, also dimensional stability to wetting and drying. Saponification may be conducted by many methods such as by the employment of caustic soda, potassium or sodium methoxides or ethoxides, organic bases, etc. This reaction may be shown structurally as follows:

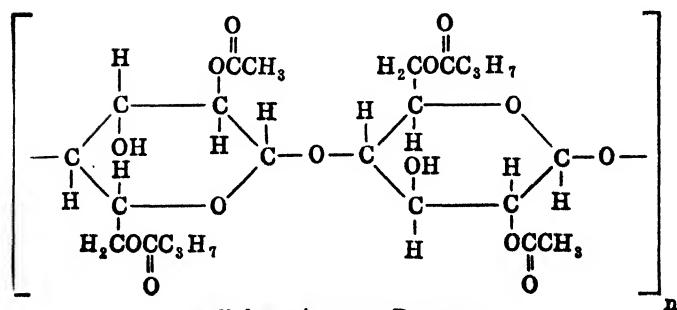
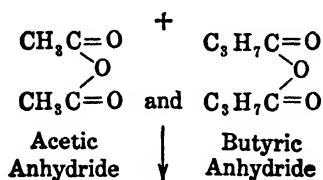


Cellulose
(Regenerated)

Cellulose Acetate Butyrate. Another cellulose derivative, cellulose acetate butyrate, can be prepared by reacting cellulose with a mixture of acetic and butyric anhydrides, in the presence of their acids, to form a mixed ester. This can be shown by the following structural formulas:

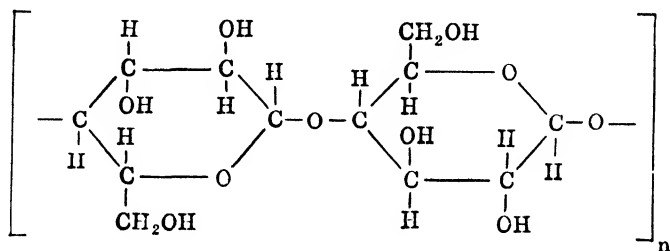


Cellulose

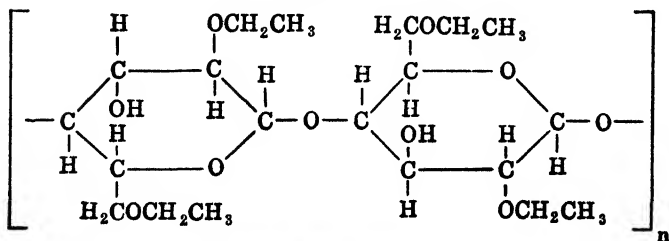
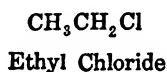
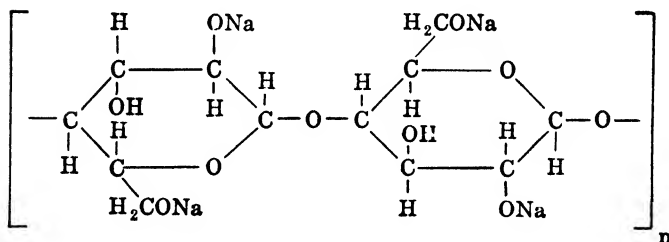


Cellulose Acetate Butyrate

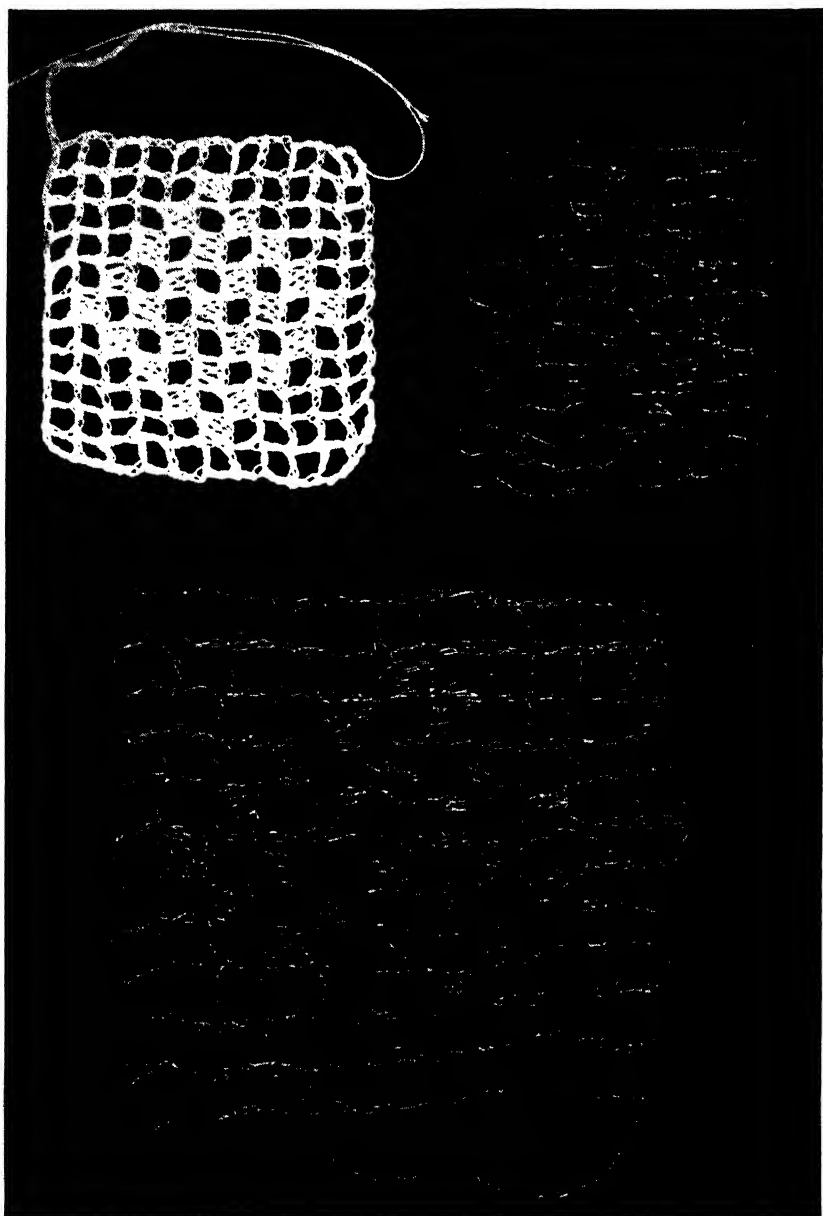
Ethyl Cellulose. Ethyl cellulose can be produced by reacting cellulose with an ethylating agent, ethyl chloride, in the presence of strong alkali, as shown by the following structural formulas:



Cellulose



Ethyl Cellulose



Courtesy Mrs. Charles M. Parker

FIG. 72. Two squares crocheted from stainless steel filaments compared with one from cotton. In these samples, stainless steel filaments having diameters of 0.0019 inch and 0.0055 inch were used.

CHAPTER XVI

Miscellaneous New Fibers

SUMMARY

In addition to synthetic, cellulosic and protein materials, fibers have been made from a wide variety of miscellaneous materials. These include aluminum, stainless steel, natural and synthetic rubbers, seaweed and even shells of certain types. Fibers made from most of these materials will probably have limited uses.

Man is not only making fibers from many types of substances never previously used for such purposes, but he is also learning how to utilize some of the natural fibers he has heretofore neglected. Ramie is coming into new prominence. Fibers from the milkweed and cattail plants, and from redwood bark, have been utilized. Recently, fabrics have been made from chicken feathers.

ALUMINUM YARNS

The use of fine aluminum yarns has extended into women's wear. Such fine strands have been made into ladies' crocheted evening sweaters, snoods, and purses. Possible applications include decorative threads in evening clothes and decorative theatrical materials. A disadvantage of aluminum yarns is that they tarnish when exposed to dampness and heat.

Two types of aluminum yarns have been developed by Reynolds Metals Company, Richmond, Va. The flat aluminum yarn is called "Reymet," and the covered yarn, "Reyspun." The flat yarn in the 1/32 inch width has a yield of 6044 yards per pound.

The yield of the covered yarn would depend entirely upon the core yarn used.

ACETATE-COATED ALUMINUM YARN

An acetate-coated aluminum yarn has recently been developed by Tennessee Eastman Corporation, working in conjunction with Aluminum Company of America and Dobeckmun Company. The metallic yarn is composed of a layer of fine aluminum foil to both sides of which a thin layer of transparent acetate film is fastened with a transparent adhesive.

If colorless and clear cement is used, the yarn resembles silver; if a yellow-orange cement is used, the result is a golden yarn. A yarn of any other color can be made by incorporating the desired color into the cement; or the material can be dyed with acetate dyes.

The material is laminated in 14-inch bands having a thickness of 0.003 inch and is then slit to individual ribbon-shaped monofilaments or yarns in widths ranging down to 1/64 inch.

These flat metallic yarns are used either alone or after twisting in a spiral around a cotton or other textile core thread. The acetate-coated aluminum yarn can be woven into fabrics in 100% form. It can also be blended with acetate rayon to form novelty fabrics. Blends with rayon weave well and have better draping qualities than the 100% material.

The yarns can be stretched, but as the aluminum does not stretch as much as the acetate, the acetate film is shattered. This is noticeable under magnification.

Acetate-coated aluminum yarns are expected to find applications in evening wear, shoes, handbags, draperies, and other uses where lamé has been used or would be used if it were not so expensive. The new material is not only lower in price than lamé, but it does not tarnish and maintains its beauty of color. It can also withstand mild washing or wet finishing operations.

STAINLESS STEEL MONOFILAMENT

One of the newest filaments is that made from stainless steel. Prior to the war, it was used in bolting cloth for flour screening and also in sifting screens for the dye and chemical industries, because of its excellent resistance to corrosion.

During the war, stainless steel monofilaments were used in blood plasma screens. These screens had 200 holes per linear inch, or 40,000 holes per square inch.

Stainless steel monofilament is made from steel containing 18% chromium and 8% nickel (the so-called 18-8 type). It has been drawn down to the following diameters: 0.0011 in., 0.0014 in., 0.0019 in., 0.0021 in.

Tensile strength is reported at 119,000 lbs. per sq. in., and elongation at 25% in 8 in. (includes both elastic and plastic deformation).

Stainless steel monofilament received some publicity in connection with a possible use for hosiery, but it is believed that its applications will be confined to the industrial field, particularly for use in screening.

FIBERS FROM SEAWEED (ALGINATES)

A new family of fibers derived from seaweed have been under development in Great Britain since 1939.

Dry seaweed contains from 15 to 40% of a chemical, known as alginic acid, which is closely related to pectic acid and cellulose. Alginic acid is readily extracted from seaweed, which is abundant off the west coasts of Scotland and Ireland. As an acid, it combines with various metals to form salts, many of which yield highly viscous solutions suitable for fiber formation. Fibers can be made from alginic acid, as well as from the alginates of calcium, beryllium, and chromium.

Alginic acid and calcium alginate fibers dissolve readily in very dilute alkaline solutions, but this property has been turned to advantage. Cotton and other yarns of very low twist can be

made by using a holding thread of alginate fiber, which is later dissolved away. Woven and lace fabrics can be produced with cotton and alginate fiber threads. A patterned material of unusual design remains after the alginate fiber threads have been dissolved away.

Considerable alkali resistance can be imparted to the alginate fibers by suitable chemical treatment. Thus, alginic acid fibers and calcium alginate fibers can be made alkali-resistant by treating them with the basic acetates of chromium and beryllium.

Their metal contents give the alginate fibers relatively high specific gravity (about 1.75), but make them nonflammable.

All the alginates are highly hygroscopic, having a far greater affinity for water than other textile fibers. In general, the water adsorption capacity rises with increasing metal content.

The tensile strength of the alginic acid fiber decreases sharply as the relative humidity rises, until, at saturation, its strength is negligible. Likewise, the wet strength of calcium alginate is only a fraction of its dry strength, but its extensibility increases steadily with rising relative humidity.

The chromium and beryllium alginate fibers have greater wet strength, but this advantage is offset by low extensibility, even in water. The extensibility of chromium and beryllium alginate fibers is too low even to permit their successful use in weaving and knitting.

Calcium alginate fibers, however, possess satisfactory elasticity and can be woven and knitted into fabrics. These fabrics can be used for special purposes in which alkali-solubility is an advantage, or they can be made alkali-resistant, as already mentioned.

Alginate fibers have a marked affinity for basic dyes and also can be dyed with selected direct dyes. The chromium and beryllium alginate fibers can be dyed with mordant dyes.

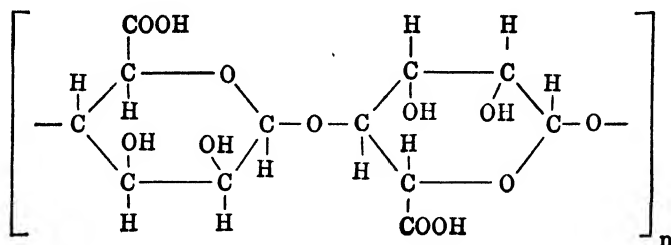
It is too early as yet to appraise the general position of the alginate fibers, since they are still in the development stage and have a number of difficulties to overcome. One difficulty is the tendency of the freshly-formed filaments to stick together.

TABLE 16.1. COMPARISON OF ALGINATE FIBERS*

	<i>Alginate acid</i>	<i>Calcium alginate</i>	<i>Aluminum alginate</i>	<i>Chromium alginate</i>	<i>Beryllium alginate</i>
Metal content	0.1% ash	10.38% Ca	3.30% Al 5.50% Ca 1.773	1.53% Cr 8.29% Ca 1.780	2.98% Be 4.91% Ca 1.735
Specific gravity	1.627 (dry) 1.558 (conditioned)	1.779			
Tenacity % RH (gms./denier)	2.00 0.50 Too weak to determine	2.18 1.14 0.29	.....	2.02 0.99 0.68	2.80 1.56 1.08
Extension % RH at break	9.7 4.3 Too weak to determine	10.1 14.3 25.7	.....	5.6 4.2 4.5	3.9 5.2 3.2
Water adsorption % RH at 65% RH .....	.....	20.4	28.5	29.1	24.9
Effect of heat	Will not burn	51.9	51.5	61.8	53.0
Effect of alkali	Dissolves	Will not burn Dissolves	Will not burn More resistant. Dissolves in 1 hr.	Will not burn Highly resistant	Will not burn Highly resistant
Effect of age	Deteriorates greatly after about 130 days	Stability increased with increasing pH	.....	Improved during storage at 65% RH and 22.22° C.	Improved during storage at 65% RH and 22.22° C.

* Source: "Alginate Fibers Compared," O. K. Tseng, *Textile World*, Vol. 95, December 1945, p. 113.
RH = relative humidity.

Chemistry. Alginic acid is a polymer of d-mannuronic acid. It has a high molecular weight ranging from 48,000 to 185,000. A suggested structural formula for alginic acid is



Alginic Acid

CHITIN

A raw material which has been mentioned occasionally during the past 20 years is chitin, which occurs in the shells of lobsters, crabs, and certain insects. While its fibrous molecular structure is probably suitable for fiber making, the problem of collecting the shells economically in sufficient quantities is an obstacle to the commercial practicability of this type of fiber.

ELASTIC THREADS

The shortage of natural rubber latex during the war forced manufacturers of elastic threads to turn their attention to various types of synthetic rubber. Of these, Neoprene proved the most generally satisfactory and was used in considerable quantities for making elastic threads.

To alleviate shortages of Neoprene, GR-S rubber was offered to the elastic thread industry, but very little work has been done on GR-S rubber thread. It is said that at the present stage of development, GR-S and GR-N are not suitable for making good elastic threads. Butyl rubber is considered to have possibilities for making thread.

Whether synthetic rubbers will be used for making elastic thread, when natural rubber becomes available again in sufficient quantities, is considered quite doubtful.

Manufacturers of elastic threads include United States Rubber Company, The B. F. Goodrich Company, Firestone Tire & Rubber Company, Easthampton Rubber Thread Company, Para Thread Company, Inc., and Carr Manufacturing Company.

Elastic thread in the uncovered form is used in narrow braids and webs. Covered with cotton or rayon, it is used for webbing and for girdles, bathing suits and other elastic garments, as well as for shoe linings.

ASBESTON

"Asbeston" is the trade name for a new type of asbestos-cotton yarn, fabric, and tape produced by United States Rubber Company. It was developed to meet the need for light-weight, high-strength asbestos yarns and fabrics.

It was introduced in 1941 and used in Army and Navy fire-fighting suits and other war applications where light, strong asbestos fabrics proved superior to the heavy, bulky fabrics formerly considered essential.

In the manufacture of Asbeston, the best grades of asbestos fiber, imported from Canada, South Africa, and Russia, are blended with from 8 to as much as 20% of cotton, added to facilitate handling of the asbestos in the manufacturing process.

Asbeston fabrics range from 8 ounces to 26 ounces per square yard, with thicknesses from 0.012 in. to 0.050 in. The tensile strength varies according to construction from an upper extreme of 157 lbs. per in. along the warp and 101 lbs. per in. along the fill, to a lower extreme of 35 lbs. and 18 lbs., respectively.

The fabrics can be coated or impregnated with resins or given special treatments for certain applications such as water-repellent treatment for fire-fighting suits, or lacquer coating for sealing against heat loss on compressible, tubular woven, hot air ducts.

*Established Applications of Asbeston**Yarns*

Woven cloths and tapes

Steam and flame retardant hose, packings and gaskets (used by the Mechanical Goods Division of United States Rubber Company)

Fabrics

Fire-fighting suits

Domestic ironing board covers

Covers for electric ironer mangles

Pipe lagging cloth (used in Navy and maritime vessels and industrial power plants)

Safety clothing—gloves, aprons

Dust and fume collecting bags

Tapes

Electrical insulation—coil winding for electric motors and cable insulation.

Braided tubing

Braided wicking for cigarette lighters

Electrical sleeving for wire insulation

Insulation jackets

Impregnated and coated fabrics

Multi-flex hot air ducts—Neoprene impregnated

Tubular woven compressible air ducts—lacquer coated

Conveyor belts for food processing—resin impregnated

Electrical insulation—varnished cloth

*Potential Applications of Asbeston**Yarns*

Sewing threads for fireproof materials

Tying cords for electrical use

Fabrics

Fireproof draperies for theaters, restaurants, night clubs, hotels, ships, etc.

Cloth covers for pressing machines in commercial laundries

Chemical filter cloths

Plastic reinforcement and laminate material

Combination fabrics and tapes

Asbeston glass inserted yarns made into a combination fabric (mainly in high temperature applications)

Asbeston glass inserted yarns made into combination tapes for electrical insulation

* Source: United States Rubber Co.

NEW COMMERCIAL NATURAL FIBERS

Mankind has utilized altogether 128 different natural fibers. Only about 18 of these, however, have attained a degree of commercial importance. The 10 at the top of the list have accounted for around 95% of total world production of all fibers. In the unceasing competition among fibers, some have been held back by inferior properties; others by high costs of production and processing.

RAMIE

The reader may wonder why a book on new fibers includes a discussion of ramie, a fiber that is perhaps as old as the mummies of ancient Egypt and one that has been known for many centuries in the Orient. The answer is that recent developments may give ramie a new importance as a textile fiber.

Although ramie has many excellent properties that qualify it for use in the field of textiles, it has not yet attained much commercial importance, because of difficulties intervening between the growing of the plant and the delivery of the fiber to the textile manufacturer. These difficulties either have been overcome in recent years or are well on the way to solution. The problem of mechanical decortication of ramie has been solved commercially and a fiber of the highest grade produced. As a result, there has been a great deal of interest in ramie and considerable acreages in Florida and other Southern States have been or are being planted with ramie.

An examination of the properties of ramie fiber indicates that there is considerable basis for this revival of interest.

Of all the natural fibers ramie is one of the strongest, having a higher tenacity than cotton, silk, and even hemp, which, like ramie, is a bast fiber. The tenacity of ramie is approximately 6.7 grams per denier. The elasticity of ramie is about equal to that of cotton. Ramie is, however, much less elastic than silk. The torsion strength of ramie is slightly greater than that of either flax or hemp, but is much less than that of cotton or silk.

Ramie fiber's unusual strength and toughness make it one of the most durable fibers, and fabrics made of it are said to wear indefinitely.

Another quality of ramie that makes it unique among fibers is its behavior when in contact with water. Ramie is more absorbent than cotton, holding water to the extent of 28% of its dry weight, whereas cotton holds water to the extent of 26%. Moreover, instead of losing strength when wet, as do many fibers, ramie is 30 to 60% stronger when wet than when dry. It dries more rapidly than does flax or cotton. It has the additional advantages of being nonshrinkable and of being highly resistant to mildew as well as to the attack of microorganisms that cause rot.

When thoroughly cleaned of gums and pectins, the fiber is pure white, without bleaching, and has an almost silk-like luster and texture. It takes dyes well and holds its color better than most other fibers. Ramie fiber can be spun, woven, and knitted on standard textile machinery and can be made into fabrics resembling gossamer-like silks, fine cotton cloth, woolen goods, linen, and others including the coarsest kinds of cloth.

Its qualities suggest a wide field of usefulness. At present there is a large demand for the fiber for the production of mechanical packing, because of its high durability combined with flexibility, watertight, nonshrinkable properties, resistance to deterioration due to sea water and high tensile strength when wet.

Such properties have led to its use for marine cordage, fish lines and nets, and sail cloth which can combine lightness with strength. Tents and tarpaulins made of ramie neither mildew nor rot.

In Europe, ramie is being used for making fire hose, mechanical belting, rugs and carpets, plushes and upholstery covers, and draperies. In the United States, it has been used with marked success for making incandescent gas mantles and filter cloth for the air-conditioning industry.

In the tire-cord field, now being contested by cotton and rayon, ramie may enter as a third contender. The chief disadvantage of ramie as compared with cotton for use in tire cord is its low torsion strength. In the opinion of some tire manufacturers, however, this obstacle is not considered insuperable but one which may possibly be overcome by further research.

Ramie is also well adapted for use in certain types of wearing apparel, particularly light-weight summer suits. Blended with other fibers such as rayon, cotton, and wool, the use of ramie makes possible many attractive new fabrics.

CATTAIL FIBER

Everyone is familiar with the common cattail which abounds in swampy lands, but not everyone knows that within recent years its fiber has become of commercial importance. The fiber is sold by Burgess-Manning Company, Chicago, under the trade name of "Typha," derived from the scientific name for the cattail plant. Typha is a natural, light-weight, cellulosic fiber which is taken from the "spike" (seedpod) of the plant.

Considerable testing and experimentation with cattails were carried on for a number of years by the C. F. Burgess Laboratories, and in the spring of 1942, an attempt was made to produce Typha commercially. A pilot plant was set up at Ashippun, Wis., which processed cattails from nearby swamps. This factory, supplemented by an additional plant at Holt, Minn., has been producing Typha in quantity from raw material shipped in from Midwestern States.

Cattail fibers have certain inherent characteristics which have adapted them for a number of uses. The multi-cellular construction of the fiber and its surface resistance to water give it a high

degree of buoyancy. It also has good thermal-insulating and sound-insulating qualities. It is claimed to have 90% of the warmth-retaining ability of wool and to be lighter in weight.

During the war, Typha was used as a filling material in seat cushions of airplanes and amphibious vehicles, as well as in air-



Courtesy Burgess-Manning Company

FIG. 73. Typha makes a good stuffing material for cloth toys.

plane tow targets and in life preservers. The entire output was devoted to military needs.

Typha is now used commercially as a filling material for various articles.

MILKWEED FIBER

Milkweed fiber is not a new fiber in the strict sense of the word, since it was used in prehistoric times in North America

and in Africa—the two areas where many species of the plant are indigenous. It has had a long and varied history of experimentation. During the war, interest was renewed because the floss of the common milkweed is similar to kapok.

As an outgrowth of research work by Dr. Boris Berkman, commercial quantities of milkweed floss were produced by the Milkweed Floss Corporation at Petoskey, Mich. Output of the floss during the war was utilized as a substitute filler for kapok in lifejackets.

It was planned to continue production of the floss for such commercial uses as filler for pillows, bedding, toys, and lining for clothing. The utilization of seeds, stalks, and leaves for making various products was also contemplated.

The fibers from the stalks are said to have possibilities for textile purposes. The English textile fiber, "Cotine," has been identified as a cottonized milkweed bast fiber.

CHICKEN FEATHERS

United States Rubber Company has developed a new fabric made principally from chicken feathers which is designed for use in suits, dresses, sweaters and other wearing apparel.

The new fabric looks like wool, and it is warmer, softer, and lighter than wool, according to Dr. W. A. Gibbons, research director of the company. It can be dyed any color and possesses a brilliant luster. It is odorless and can be laundered in soap and water with no more shrinkage than cotton. The feathers are particularly adaptable for admixture with other staple fibers, such as rayon, cotton, wool and nylon. The feather content of fabrics produced in the laboratory ranged from 60 to 70%.

In the production of the yarn, the first operation is the separation of the fine elements of the feathers from the quills by a machine especially designed for this purpose. The quills are discarded and the fine elements, called barbs, are mixed with other fibers and spun into yarn by a special process. The yarn is then woven into cloth.

It is estimated that 170 million lbs. of chicken feathers and 30 million lbs. of turkey feathers are wasted in the United States every year. In addition to feathers from chickens and turkeys, those from ducks, geese, and other fowl can be utilized for making fabrics.

REDWOOD BARK FIBER

The giant redwood tree, which grows near the Pacific coast, has been utilized as a source of fibers. The fiber represents approximately 25% of the bark of the redwood tree, and it is this fiber which has become of commercial interest, not the fiber from the wood itself. The idea of using this by-product of the redwood lumber industry for textile purposes resulted from the discovery of the felting characteristics of the short fibers in the bark. They collected in mats and spun balls on the screen-belts which segregate the long fibers used for insulation.

The development work on redwood has been carried out at The Institute of Paper Chemistry, Appleton, Wis., for The Pacific Lumber Company of California.

Redwood bark fiber is one of the few natural cellulosic fibers which have felting characteristics. The corkscrew nature of the fiber enables it to felt well. It is also one of the few natural fibers which can be recovered with its continuous film of lignin. This makes it sufficiently acid-resistant for application where acid-resistance is important.

A series of tests carried out in conjunction with a leading wool company showed that the redwood bark fibers interfelt and intermat with wool fibers to form a strong fabric. Redwood bark fiber is said to be highly resistant to humidity and to retain its natural resilience after processing with wool.

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Milkweed Fiber

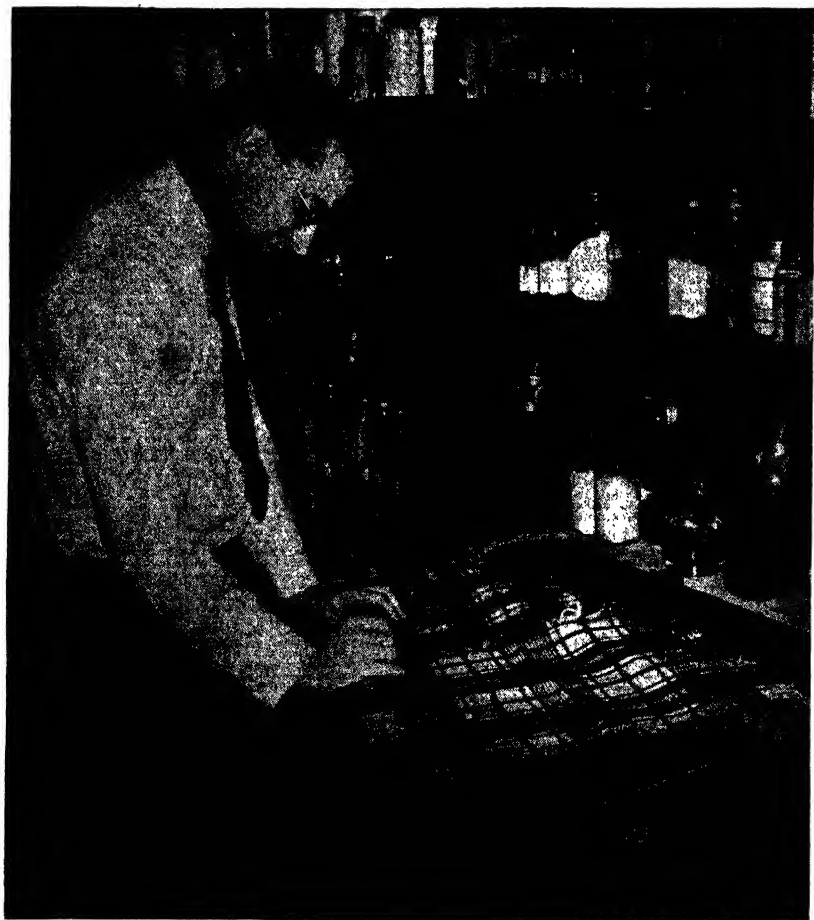
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Courtesy Monsanto Chemical Company

FIG. 74. Two swatches of woolen fabric, once of identical size, are studied by Dr. Donald H. Powers. The larger one, having been Resloomed, did not shrink at all; the untreated swatch lost about half of its original width and one third its original length.

CHAPTER XVII

Chemical Treatments of Textiles

SUMMARY

One phase of the chemical revolution in textiles started with the creation of new fibers. Another and recent phase involves the application of chemistry in improving the older fibers.

While the synthetic fibers are outstanding in certain specific properties, none of them can yet compare with cotton in over-all adaptability and price; and not one of the new protein fibers has demonstrated its ability to take the place of wool.

This does not mean, however, that the natural fibers will remain generally superior. The new fibers were all created through research effort and are being improved at a much more rapid rate than the natural fibers. Every fiber has its limitations and disadvantages and must be improved continuously if it is to maintain its position in the textile world.

Chemical treatments are the cotton and wool industries' answer to the threat of the new fibers. Only by offering better cotton and wool can these industries hope to keep up with the pace set by their new competitors.

Such improvements have been made possible through the development of a number of new resins in recent years. These impart to the natural fibers certain properties in which they are deficient. Cotton that has been chemically treated to make it stronger, or wool that has been treated to make it shrinkproof, is no longer a natural fiber. It is a very unnatural one and a new one, too!

IMPROVEMENTS IN THE NATURAL FIBERS

In the coming competition between the natural and the man-made fibers, the former will have to be improved radically if they are to maintain their markets. This can be accomplished in a number of ways. Anything that tends to improve the properties of a fiber, or to adapt it to new uses, or to reduce its cost of production, will help to strengthen its competitive position relative to other fibers.

Improvements in the natural fibers can occur anywhere along the line of production which extends all the way from the farmer to the textile finisher. For example, the use of a mechanical cotton picker, by reducing the production costs of cotton, might help greatly to better the competitive position of cotton with respect to rayon, which is now competitive with cotton on a price basis. Utilization of more efficient processing machinery could have a similar effect in reducing operating costs. But perhaps the most promising developments from the standpoint of the natural fibers involve the use of chemical treatments.

Through the use of plastics and other chemicals, a wide range of new and improved properties may be imparted to the natural fibers. Every important type of plastic is being utilized at least experimentally in work now under way with fibers and textiles. The development of a number of new types of plastics in recent years has extended greatly the possibilities. Considerable work has been done in the application of the relatively new melamine resins.

The silicones are also considered to have revolutionary possibilities for textiles, but it is too early as yet to state with any degree of finality just what their importance may be. Still other materials are under investigation.

Among the chemical companies, Monsanto Chemical Company and American Cyanamid Company have been particularly active in the development of new chemicals for treating textiles. It might be interesting at this point to quote a recent statement of Edgar Monsanto Queeny, chairman of the board of directors of Monsanto Chemical Company:

Suits that have been Resloom treated, through use of new synthetic resins developed in Monsanto textile laboratories, will not have to be pressed nearly as often as those you wear today.

All-wool socks or sweaters, Resloomed, will not shrink or mat even if the laundress washes them in scalding hot water.

Hosiery, even the sheerest silk, will be much less likely to develop runs after treatment with Syton—which is a new form of inorganic resin, also the product of our laboratories.

Still another application of Syton is for the increasing of wear resistance in a wide range of fabrics from overall denims to sheer, summer dress materials.

Rainwear, sportswear and children's outer clothing will be made virtually weatherproof, creaseproof and stainproof by a new, permanent, water repellent finish with many clear advantages over any similar type finish yet developed.

All of this means that the natural fibers will be capable of putting up a terrific battle before yielding ground to the synthetics. There are two schools of thought in the industry. One holds that the natural fibers will gradually lose more and more markets to man-made fibers, particularly as the cost of producing the latter is lowered. The other school of thought believes that the natural fibers will generally maintain their competitive position as the result of improvements in properties and new production economics.

Regardless of which view proves to be correct, it is safe to predict that the time will come when most of the fibers used will be either man-made fibers or man-improved fibers. In this sense, the new fibers of today will probably be the standard fibers tomorrow.

CHEMICAL MODIFICATIONS OF FIBERS AND FABRICS

The use of synthetic resins for the modification and improvement of textile fibers and fabrics attained considerable importance during the war and gives every indication of assuming much larger proportions in the future.

Such applications have been along three distinct lines, where the effects produced are entirely dependent on the physical form in which the resin is applied. It is possible to apply the same

resin in all three methods, although usually distinct and different types are used.

The three basic methods are the following:

- (1) Coatings or surface sizings;
- (2) Impregnations;
- (3) Fiber saturation or resin formation within the fiber.

The coatings are the oldest and best established, and the fiber saturations are the newest. The different methods are not directly competitive, as each has its own particular field of application.

In the prewar years, coated fabrics were to a large extent rubberized or solvent-coated with plasticized nitrocellulose or with drying oils. When a critical shortage in rubber occurred during the war, substitutes had to be developed rapidly. One of these was plasticized polyvinyl chloride acetate copolymer which gives coatings of excellent flexibility at low temperatures. Another was polyvinyl butyral which can be handled like rubber and gives unusually flexible and durable coatings. The softness and durability of the polyvinyl butyrals make them of particular value for coating fine fabrics and for the development of new types of coatings on novel fabrics. The development of butyl rubber as an adhesive for two-ply fabrics has also given promising results.

One of the most important coatings during the war was for fireproof, mildewproof tent duck developed for the Army. The combination of chlorinated paraffin and antimony oxide for fire resistance and copper naphthenate for mildew resistance, together with colored pigments for shade, held in with resins of low inflammability, gave a general utility fabric which was used in large quantities. Ultimately a higher fire resistance may be developed with a lower concentration of solids. Making textiles fire-resistant or fireproof is considered one of the most important objectives.

Prior to the war, rubber latex found an important use in impregnating the back of pile fabrics, particularly automotive upholstery. The war cut off both the supply of latex and the demand for it in automotive upholstery. Synthetic rubber latex, when it is not heavily compounded, is not in any sense equal to

natural latex. Water dispersions of polystyrene, polyvinyl chloride, polyvinyl acetate, or polymethacrylate may replace a portion of the latex market. Resin dispersions of polystyrene and of polyvinyl butyral have shown unusual promise for improving the wear resistance of cotton fabrics for work clothes and the like.

Studies of wear resistance indicate that in many cases the wear can be more than doubled with not more than from 2 to 5% increase in weight by the impregnation of resin. It is believed that the use of resin impregnations to improve the wear resistance of children's play suits, farmers' work clothes, and mechanics' uniforms will become increasingly important. Resin impregnations are also finding greater use where decreased permeability of fabrics is desired for better repellency and proofness. With the softer fabrics resin impregnations yield marked increase in strength and in some cases give some shrinkage control.

A new material possessing unusual characteristics for use in treating textiles is the colloidal silica developed under the trade name of Syton. It is used for slip-proofing and run-proofing. This sub-microscopic water dispersion of a special type silica polymer has proved of value for reducing the slippage of sheer rayons and nylons. Syton might be described as an "anti" lubricant, as it imparts increased friction in extremely low concentrations to all types of fibers. It is possible to improve the strength of soft twist fabrics by after-treating with Syton, as it reduces the loss of strength due to slippage. It is suggested, however, that best results would be obtained if the colloidal silica could be applied after combing or carding but prior to spinning.

Another class of resins, the melamines, are unique in their resistance to water and alkalies and it is only natural that they should be considered for waterproofing. Water dispersions of the low-polymer methylol melamine derivatives give excellent water-repellent finishes which are fast to washing and dry cleaning, while still allowing the fabric to "breathe."

In cases where this resin is formed within the fiber, the fabrics, even under the microscope, look like untreated, unmodified fabrics. The individual yarns can be separated without any sticking,

and even the individual filaments or fibers can be untwisted and pulled apart just as in an untreated fabric. Moreover, the treated fabrics feel as soft as and even more resilient than untreated fabrics.

In treating fabrics with melamine resins, the following three conditions must be met and carefully controlled in order to get satisfactory results:

- (a) The fabrics are treated with a solution which swells the fibers;
- (b) The resin forms a true solution and is applied as a completely unpolymerized monomer;
- (c) Excess resin solution is removed from the surface and between the fibers before the resin monomer is polymerized.

In the cases of rayon and wool, for example, the swelling agent is most conveniently water. The melamine resin may be prepared as a truly water soluble monomer which penetrates the fiber when it is swollen. The excess of surface resin solution is removed by wringing out the fabrics through very tight squeeze rolls. The resin is deposited in the core of the fiber by drying and heating to 275° to 300° F. The high temperature polymerizes it to a water-insoluble washfast form. Careful microscopic examination shows that the resin polymer is evenly distributed throughout the fibers. Melamine resin appears to be unique in its ability to penetrate cotton, rayon, wool, and casein fiber.

One of the earlier types of fiber impregnation is the Tootal-Broadhurst Lee process which was developed in England. This process consisted in treating rayons with a water solution of dimethylol urea, an unpolymerized resin which could be heat polymerized after saturating the rayon. More recently the aqueous urea formaldehyde resin solutions have been developed for reducing the shrinkage of rayons and for producing a durable "glazed chintz." In the latter case the resin is kept on the surface of the fabric and is polymerized during friction calendering.

The methylol melamines can be used to distinct advantage on cotton and rayons. They appear to be unique in their ability to stabilize wools and worsteds, reducing their felting and making it possible to wash these resin-modified fabrics without excessive shrinkage. The rayons so modified take on much of the resilience of wool; the wools so modified take on much of the washability and shrinkage resistance of cotton.

In a similar manner, other characteristics can be imparted to fabrics by chemical treatments. These include crush-resistance, stabilization, shrinkage control by setting and stabilizing the fabric, giving the fabric "a memory" for former, set position, etc.

Chemical modification of fibers and fabrics can usually be achieved without any sacrifice of desirable qualities. Thus, their tensile strength should not be impaired under normal mill conditions. While resins have no effect on light fastness, they improve wash fastness.

TABLE 17.1. EFFECT OF RESINS ON COTTON SHEETING*

<i>Treatment on sheeting</i>	<i>Concn. of resin former in water (%)</i>	<i>Shrinkage of fabric on washing (%)</i>	<i>Tensile strength (Scott tester)</i>	<i>Abrasion (Taber abrader)</i>
None	0	5.2	41.5	6557
Urea-formaldehyde	5	2.8	37.5	4730
Phenol-formaldehyde	5	3.0	41.3	7780
Melamine-formaldehyde	5	1.8	40.8	6400

* Source: D. H. Powers, *Ind. & Eng. Chem.* 37, 188, February 1945.

SYNTHETIC RESIN TREATMENT OF COTTON

Various types of synthetic resins, natural resins, and other bonding agents have been added recently to cotton technology. So successful has been their application that entirely new concepts of the characteristics and uses of cotton rovings,¹ yarns, and fabrics have entered into the calculations of textile engineers.

¹ Roving—a loose assemblage of fibers drawn or rubbed into a single strand, with very little twist. An intermediate stage between sliver and yarn.

TABLE 17.2. EFFECT OF RESIN CONCENTRATION ON TENSILE STRENGTH* †

Bleached cotton sheeting			All spun rayon		All wool flannel
% Resin in fiber	Methylol- urea†	Methylol- melaminet	% Resin in fiber	Methylol- urea†	Methylol- melaminet
0	90	90	0	85	46.6
1	88	96	1	89	63.4
3	86	95	3	96	62.7
7	70	90	5	89	59.0
10	67	83	10	88	45.1
15	65	88	15	85	....
..	..	..	20	78	....

* Source: D. H. Powers, *Ind. & Eng. Chem.* 37, 188, February 1945.

† Tensile strengths are the sum of warp and filling breaks. Figures are the average of five breaks taken on samples after conditioning for 24 hours.

TABLE 17.3. CHANGE IN TENSILE STRENGTH RESULTING FROM
RESIN IMPREGNATION*
(Expressed as Per Cent Change)

% Resin concn.	Impregnated with methylol- melamine			Impregnated with methylol-urea	
	Cotton	Spun rayon	Wool	Cotton	Spun rayon
5	2	9	36	-15	4
10	0	18	34	-24	3
15	-2	36	30	-27	0

* Source: D. H. Powers, *Ind. & Eng. Chem.* 37, 188, February 1945.

TABLE 17.4. SHRINKAGE OF FABRICS BEFORE AND AFTER RESIN
TREATMENT*

Fabric	Original shrinkage	Resin † (%)	Shrinkage after resin impregna- tion	Shrinkage removed (%)
Light cotton sheeting	6.74	5.2	1.09	84
Heavy cotton sheeting	5.58	4.8	1.17	79
Cotton flannel	12.6	5.5	2.1	84
Cotton lawn	3.4	4.3	0.8	77
All spun rayon	12.1	6.1	2.9	76
Filament rayon	11.4	5.9	4.3	62
Cotton-rayon-wool blanket	19.4	10.6	3.2	84
Cotton-rayon blanket	20.2	5.8	6.8	66
All-wool challis	23.2	6.2	5.7	75
All-wool flannel	30.1	10.8	4.1	86
All-wool shirting	20.7	5.7	6.1	71
Wool-rayon shirting	24.2	12.8	4.8	80
All-wool suiting	11.5	7.2	3.2	72
Cotton-rayon suiting	11.4	8.9	1.7	85
				Av. 79

* Source: D. H. Powers, *Ind. & Eng. Chem.* 37, 188, February 1945.

† Methylol-melamine.

TABLE 17-5. EFFECT OF RESIN ON MOISTURE PICKUP*

Resin used	Cotton sheeting		Spun rayon		Wool flannel	
	% Resin	% Moisture regain at 66% rel. humidity †	% Resin	% Moisture regain at 66% rel. humidity †	% Resin	% Moisture regain at 66% rel. humidity †
Methylol-melamine	.....	5.88	....	11.66	....	10.32
	1.0	5.87	1.2	11.00	9.6	10.52
	2.4	5.41	3.0	10.95	....	....
	5.0	4.69	6.1	10.42	....	....
	10.0	4.48	12.0	10.12	....	....
Methylol-urea	2.3	5.49	7.2	10.34	6.4	10.62
	5.6	5.14	....	....	....	....

* Source: D. H. Powers, *Ind. & Eng. Chem.*, 37, 188, February 1945.

† Moisture regain is figured on the weight of the dry fiber.

The processes for applying synthetic resins to cotton have been pioneered by Riverside & Dan River Cotton Mills, Inc., of Danville, Va., for many years a dominant factor in the production and marketing of a wide variety of textile products.

Up until recent years, the cotton manufacturing industry had come to rely almost entirely on the mechanical engineer and the textile physicist for improvements and developments. Continuous progress resulted in faster and cheaper spinning; looms were built to have greater operating speeds. The ultimate goal was a point where every operation would be automatic, and some textile machines had already reached a point of development where little human supervision was necessary. This trend has continued, as economy in the utilization of labor is a fundamental consideration in every industry today.

The physicist also contributed much to the study of the cotton fiber and set standards for its improvement by the growers.

But it was only in the dyeing and finishing branches of the textile industry that chemical processes played an important part. Great advances have been made in recent years in textile color work, and in the speed with which it can be performed. The production of fast colors in cotton textile products has approximated a precision operation. Finishes have been imparted to all kinds of cotton fabrics that give them a much wider field of application and restore them to a position where they can meet the competition of manufactured fibers.

These chemical processes were confined largely to the last stages of cotton textile manufacture. Now chemistry has been brought actively into the first stages of cotton manufacture. Synthetic resins are applied to the yarn, and also to rovings, giving them great additional strength and, in the same operation, properties which heretofore had been added at the last stage of manufacture in separate and costly operations.

Application of the bonding agent technique as an early step in the manufacture of fabrics has not yet gone beyond the experimental stage. Thus far, the emphasis has been placed on perfecting yarns and cords, exploring the possibilities of various

formulations and mechanical manipulations, and the manufacture of cords having properties adapted to specialized uses. Various processed yarns and cords have proved their value for certain uses and have gone into commercial production.

Riverside & Dan River Cotton Mills is making an exhaustive study of all synthetic resins in their various combinations, including such typical resin bases as melamine formaldehyde, urea formaldehyde, phenol formaldehyde, alkyds, polyamides, vinyls, styrenes, casein, silicones, and the various elastomers which have been developed in connection with the synthetic rubber program.

Synthetic resin processes have been applied with great success in pigment dyeing² and in the treatment of netting cloths, greatly reducing their tendency to slip.

The basic process of Riverside & Dan River Cotton Mills for applying bonding agents³ to netting fabrics was used by many finishing plants during the war in the treatment of screen cloths used by the armed services for protection against insects. In this process the synthetic resins bind the crossings of the yarns without affecting the openings in the cloth in any way.

Use of the same process in the treatment of cloths made of manufactured fibers and used for underclothing and garment linings, which often slip under the stresses to which they are subjected, is in the experimental stage.

It has been common knowledge in the textile industry that the tensile strength of a cotton yarn can be increased by the application of substances that bind the fibers together. Yarns sized with starch show gains of from 15 to 30% in strength. This, however, is only a temporary gain because starch readily dissolves in water and is eliminated from the yarn before it can be put to practical use. Even when carried through in the finished fabric, the starch sizing has been regarded as an adulterant which gives fictitious body to a sleazy fabric and disappears in the first laundering.

² U. S. Patent 2,354,199.

³ U. S. Patent 2,281,830.

It has also been known that some additional strength is imparted to a yarn in the process of mercerization, even though the primary object is not to increase the tensile strength, but to enhance the appearance of the yarn, give it a glossy luster and a texture pleasing to the touch. Mercerization is a true chemical treatment which, had it been explored to the fullest extent by chemical research, might well have revealed the secret of the process that finally was disclosed by combining synthetic resins with certain physical manipulations of the yarn.

In the early 1930's, synthetic resins ⁴ were first applied to yarns which were then stretched and cured in a tensioned state. This gave remarkable increases in tensile strength. At the same time, a cotton tire cord ⁵ of high strength was produced by employing a tensioning technique after thorough saturation of the cord with water. After aging, the cord was again tensioned and dried in the tensioned state. Because of its high tensile strength this cord became a commercial success.

The first commercial application of resin-treated yarn was to threads used in sewing shoes, where gains in tensile strength as high as 70 to 80% were achieved. The process left little stretch in the thread and made it comparable in general properties with linen thread, which previously had been the standard for certain shoe-sewing operations.

The solution of production problems connected with the new process took considerable time, and it was not until the middle of 1944 that the products made under the process were announced to the industry by Riverside & Dan River Cotton Mills.

At that time the process had been applied commercially only to conventionally spun yarns, though research had been going forward on a new article of manufacture—a yarn or cord produced directly from cotton roving by the same resin and tensioning process. The gain in comparative tensile strength of the roving was great and at the same time a yarn was produced that was remarkable for smoothness and uniformity.

⁴ U. S. Patent 2,220,958.

⁵ U. S. Patent 2,103,218.

The same process is employed in the treatment of both yarn and roving. The roving, as it comes from the roving frame, receives a twist preliminary to processing. This twist is preferably just sufficient to obtain the tensile strength required for mechanical handling of the roving. The actual treating process begins when the spools, containing either a conventional yarn, or a slightly



Courtesy Riverside and Dan River Cotton Mills

FIG. 75. Photomicrograph of a cross section of an untreated 1.50 hank roving. It will be noted that the fibers are unevenly dispersed and that the circumference of the roving is broken and irregular.

twisted roving, are placed in the treating machine. This machine then draws the yarn or roving over a roller revolving in a bath of the bonding agent, which may be a natural or synthetic resin or other suitable bonding agent. By passing over the roller, the yarn or roving is impregnated with the bonding agent and is then wound on spools.

From these spools the treated yarn or roving is passed through a machine by which it is subjected to tensioning and compression. The tensioning is controlled by precision devices and remains constant until the bonding agent has been set or cured. Various degrees of compression may be applied.

The bonding agent is set and cured by means of a heating element, thus fixing permanently both the tension and the compression. All these processes are completed as the yarn or roving moves through the machine to the final operation of winding on standard spools.

There is a wide range of bonding agents which may be used in this process so that the properties of finished yarn or roving may be varied to meet specialized uses.

Pigments may be added to the bonding solutions to produce a colored yarn in the same operation. If desired, the yarn or roving may be coated with resins or waxes to give a smoother surface in order to permit a freer action in some types of weaving.

As to the actual physical changes brought about by this process in conventionally spun and plied yarns, and rovings, it is necessary to consider them separately, for while the treatment is identical, the changes in each material vary.

In the case of conventionally spun yarns, there are a number of improvements effected:



Courtesy Riverside and Dan River Cotton Mills

FIG. 76. Photomicrograph of a cross section of the same 1.50 hank roving after it has been treated by the synthetic resin process. The fibers are now compact and in rather dense alignment. The circumference is round and regular, which accounts for the unusual smoothness and uniformity exhibited by these treated rovings.

(1) The tensile strength is increased from 20 to 70% over the unprocessed yarns.

(2) In the treated yarn or thread, all the individual fibers tend to take on an equal amount of the load when the yarn or thread is placed under tension in actual use. Thus the treated yarns or threads may be said to be permanently set as to equalized tension, and also as to twisting.

(3) The diameter of the treated yarn or thread is decreased, thus reducing the weight per yard compared with the untreated thread. As the surface of the treated yarn or thread is smooth, much better sewing action will be obtained.

(4) The normal stretch of the yarn or thread is reduced by from 30 to 60%.

(5) The resistance to surface abrasive wear is greatly increased.

The changes in the roving resulting from the treatment are more extensive than in the conventional yarn, largely because the roving is much more fluid in its construction than the spun yarn. It is an axiom in the textile industry that a single cotton fiber has relatively great strength compared with the conventionally spun yarn. The primary objective of the process is to bring the parallelly arranged fibers of a sliver or roving down to as small a diameter as possible, and by bonding them under tension and compression to approximate as nearly as possible a single strand.

It is possible to obtain a more uniform tensioning and parallelism of the individual fibers in a single roving unit than in a spun and plied yarn, because the drafting employed in fabricating a spun yarn brings about more irregularity than in rovings that have been drawn down and combined in a multi-ply yarn. The process brings about the following changes in the treated roving:

(1) Increased parallel arrangement of the fibers of a length of roving because of the tension applied, and the fixing of them in parallelism with the bonding agent.

(2) Compression of the parallelly arranged fibers into as

small a space as possible and fixing them in that compressed state with a bonding agent.

(3) Equalization of the tension on all the fibers and reduction of the inherent stretch; then fixing the tension and reduced stretch with a bonding agent.

Improvements resulting from this treatment of cotton roving are the following:



Courtesy Riverside and Dan River Cotton Mills

FIG. 77. Photomicrograph of a cross section of a conventional plied yarn, comprising 8 strands of a No. 12 yarn, plied in two groups of four yarns each. These two groups are then plied together as a single yarn, making what is known as 12s/4/2. This cross section has not been treated.



Courtesy Riverside and Dan River Cotton Mills

FIG. 78. Photomicrograph of a cross section of the same yarn after the synthetic resin treatment. The yarn is now compact and the circumference presents a more nearly circular, and a much more even surface, making for smoothness and uniformity.

- (1) Increases in tensile strength ranging from 75 to 100%.
- (2) Control of residual stretch to as low as 2 to 3% at the breaking point, or 1% under a 10-lb. load.
- (3) An increase in toughness of the final product by the use of certain types of bonding agents.
- (4) Elimination of the cutting and wearing action inherent in multi-plied yarns.

(5) Consistent uniformity of size and surface smoothness in the finished roving.

(6) Dyestuffs can be affixed to the roving as a permanent and uniform coloring in the one operation.

(7) Latex, wax or resin coatings can be affixed to the roving in the one operation.

The synthetic resin treatment of cotton roving and yarn has opened up a vast new field of applications. New developments in chemistry, based on polymerization, offer literally thousands of synthetics, differing in properties, from which to select the most suitable to meet any prescribed specification.

Thus, any one of a number of thermoplastic or thermosetting resins may be combined with pigment for color, chemicals for mildewproofing, fireproofing, etc. The yarns can be made soft and flexible, or hard as wire, according to the use to which they are to be put. The ultimate possibilities seem to be unlimited.

Experimental research of a somewhat limited character indicates that the same technique of applying synthetic resins to cotton roving and yarn is equally applicable to various types of rayons and other manufactured fibers. These, like cotton, may be given higher breaking strengths and other improved properties.

MELAMINES FOR TEXTILE TREATMENT

American Cyanamid's melamine product is distributed under the trade name "Lanaset" for application under a patented process (U. S. Patent 2,329,622; Reissue 22,566). It is claimed that Lanaset not only stabilizes the fibers and assures better shrinkage control, but also preserves the desirable properties of wool. Moreover, it is said to prevent such undesirable tendencies as "felting," or the inclination of wool to mat into a felt-like material after repeated washings.

Another melamine resin developed by American Cyanamid Company for treating textiles is Aerotex M-3. This has been used to prevent shrinkage of cotton and nylon insect protective netting. It is used also for creaseproofing and shrinkage control of viscose and acetate rayons. It also helps to overcome shrinkage

and wrinkling of spun rayon used for shirting and dress goods materials and the tendency of jersey knit goods to bag.

Still another melamine resin developed by this company for textile use is Permel (U. S. Patent 2,357,273). This produces a durable water-repellent finish on cotton or rayon which in no way changes the other characteristics of the material and is substantially unaffected by laundering or dry cleaning. These materials can be rendered highly crease-resistant and even spot-resistant, in the same operation. Stains that are soluble in water can be wiped off quickly and easily. This resin may find application in many other types of clothing from women's evening dresses to men's suits.

TABLE 17.6. SHRINKAGE CONTROL OBTAINED ON MILL TRIALS OF LANASET *

No. of launderings		Shrinkages † in per cent			
		Untreated		Treated	
		Warp	Fill	Warp	Fill
Cloth 1	1	2.5	0.5	2.0	0.3
	3	4.3	1.7	2.8	0.5
	5	6.3	3.2	3.9	0.5
	7	8.7	5.5	4.6	1.1
	10	10.3	8.4	5.0	0.9
Cloth 2	1	18.3	15.2	4.2	4.7
	3	22.0	18.7	5.9	5.2
Cloth 3	1	4.0	1.5	2.5	1.3
	3	6.5	3.5	3.5	2.0
	5	8.5	5.8	4.5	2.5
	10	13.0	10.5	5.2	2.5

* Source: *Calco Technical Bulletin No. 766*, Calco Chemical Div., Am. Cyanamid Co., Bound Brook, N. J.

† Samples given wool launderings 10 min. at 100° F. according to Fed. Spec. CCC-T-191A.

Cloth 1—Tropical Worsted

Cloth 2—Plaid Flannel

Cloth 3—80% Wool, 20% Cotton Army Shirting

TABLE 17.7. EFFECT OF LANASET ON WOOL PROPERTIES *

<i>Physical Property</i>	<i>Effect of Lanaset on Original Wool</i>
Crease resistance	Not changed
Felting	Very little tendency to felt left in wool
Hand	Slightly harshened—can be adjusted with softener
Moisture regain	Almost no change
Napping	Sometimes need a stronger action for same degree of napping. Napping before treating and final brushing often effective.
Resiliency	Not changed
Shrinkage	Markedly decreased
Warmth	Not changed
Dyes—Color fastness ...	Usually faster to wet treatments. Most commonly used wool dyes not adversely affected.
Shade change ...	Tests should be made, however, before going into production

* Source: *Calco Technical Bulletin No. 766*, Calco Chemical Div., Am. Cyanamid Co., Bound Brook, N. J.

TABLE 17.8. EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF WOOL *

<i>Treatment</i>	<i>Heated</i>		<i>Tensile strength—3 In. grab (lbs.)</i>			
			<i>Cloth A †</i>		<i>Cloth B †</i>	
	<i>Min.</i>	<i>Degrees F.</i>	<i>Warp</i>	<i>Fill</i>	<i>Warp</i>	<i>Fill</i>
Control	0	...	55.6	60.9	45.8	30.0
Wet out	5	290	54.9	60.3	46.3	30.3
Wet out	15	290	55.0	60.8	....	....
Wet out	30	290	53.9	61.5	46.5	30.0
Wet out	45	290	....	....	47.8	31.8
Wet out	60	290	55.3	59.0	....	....
Left dry	60	290	55.8	62.8	....	....
Wet out	9	350	....	....	45.3	34.8

* Source: "Wool Shrinkage Control with Lanaset," *Calco Technical Bulletin No. 766*, Calco Chemical Div., Am. Cyanamid Co., Bound Brook, N. J.

† Cloth A—8.5 oz. plain weave suiting, no nap. Cloth B—8 oz. women's wear flannel.

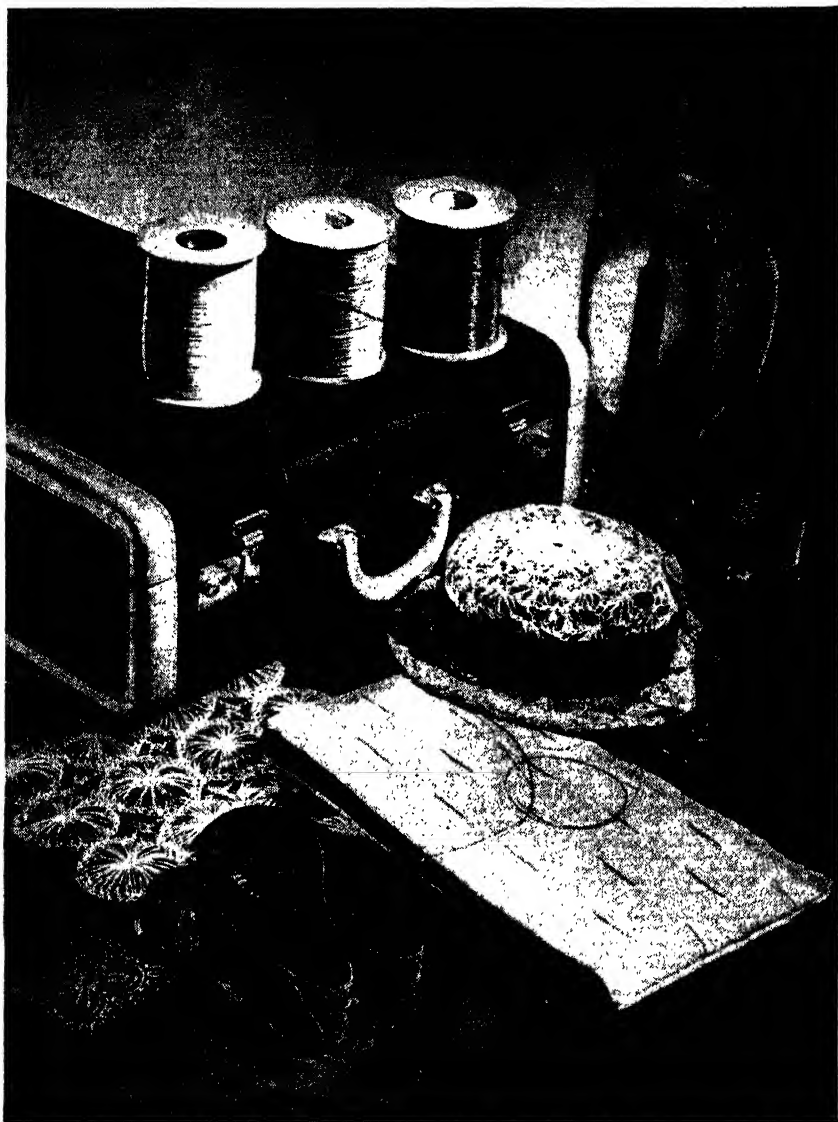
PLEXON (PLASTIC-COATED YARN)

History and Development. The process of coating yarns, now known as Plexon, originated in France in 1922. A mechanical engineer by the name of Roumazeilles, and a chemist by the name of Girard, collaborated in an attempt to produce a new type of artificial fiber to take the place of reed and rattan. They believed that by coating narrow tapes with plastic, they could produce a satisfactory substitute for reed used in the manufacture of outdoor furniture. After they developed a machine to coat heavy tapes with a series of superimposed layers of plastic, they worked out a method of coating yarns.

The original French patents were sold to the Societ  Anonyme Du Rotin, which company established a large factory and built many machines for use in coating all types of yarns. The first plastic-coated yarns made their appearance in the commercial world about 1925. The first fabrics woven from plastic-coated yarns went to the shoe trade where they met with instant acceptance. Subsequently, weavers of broad goods utilized Plexon in the manufacture of handbags, dress trimmings and other accessories.

The Plexon method was introduced in the United States in 1938. The firm of Freyberg Bros.-Strauss, Inc., of Stamford, Conn., purchased the American rights to the process and brought over one of the French machines. Here, too, the first applications of the yarn were in ladies' shoes and handbags. The success of this first venture necessitated the building of additional productive facilities and in 1942, a large number of machines of a new type were built. Great advances were made in the field of plastics making possible the use of many new types of resins in the manufacture of Plexon yarns.

The war gave an impetus to the development of Plexon, which was used as a substitute for wire in the weaving of insect screen cloth. For this purpose, a special type of Plexon yarn was developed. The new yarn, made of a cotton core and coated with cellulose acetate butyrate, was stiff and resilient and had many of



Courtesy Freyberg Bros.-Strauss, Inc.

FIG. 79. A few of the many applications of Plexon—plastic-coated yarns.

the qualities of steel wire. It simulated steel so well that it was woven successfully on standard wire cloth looms. It was rust-proof, flame-retardative, and stood up well under all weather conditions. Another development was a special type of coating for Fiberglas cord to make it abrasion-resistant and thus serviceable in the construction of ships. Plexon was becoming a tailor-made yarn.



Courtesy Freyberg Bros.-Strauss, Inc.

FIG. 80. Hand-crocheted Plexon handbags can be made in beautiful bright colors.

Properties and Applications. Plexon has many advantages which have adapted it to a wide range of applications. Its versatility of color; smooth, even finish; ability to withstand perspiration, mild acids, alkalies, grease, etc., have qualified it for use in many types of consumer goods where appearance is of paramount importance.

It has been used in the weaving of fabric for making shoes, handbags, millinery, table mats, upholstery and drapery materials. It also has been woven on narrow looms into webbing for use in making men's suspenders, men's and ladies' belts, dog leashes, costume jewelry, and dress ornaments. It has had wide application in the hand-crocheted field and in the art and crafts.

In the industrial field, Plexon has been used in the weaving of special types of fabrics for conveyor belts, filters and insect screen cloth. It has also been used for identification purposes, for tag stringing, window display and decorative uses, and in the electrical field for cable markers.

It is anticipated that plastic-coated yarns will find much wider use in the future. Fine yarns equivalent to 75 denier rayon are possible. These can be woven into sheer goods for use in the manufacture of dress materials, fabric for making curtains, material for use in making girdles, foundation garments, bathing suits, and shower curtains. The range will also be extended to very heavy types of plastic-coated yarns for use in industrial applications.

There is an unlimited list of basic materials from which to choose in making plastic-coated yarn. The entire range of plastics can be used so that yarns can be tailored to meet specific requirements. Through the utilization of a full range of resins, plasticizers and solvents, there are almost infinite possibilities as to the type of finish that can be developed. The precise quality desired can be incorporated into the yarn. For example, the yarn can be given a flame-proof coating.

The range of finishes too can be widely extended. In addition to the smooth, highly lustrous finish already familiar in plastic-coated yarns, soft mat finishes, and rough or homespun finishes can be produced.

An unlimited range of shades and tints is possible. The colors can be made fluorescent so that they can be seen readily in the dark. Also, the yarn can be made transparent, translucent or opaque.

Plastic-coated yarn is actually a multifilament that has been made into a monofilament. It has the *inherent advantages* of most monofilaments without the loss of any of the advantages of the multifilament. It can be woven easily and quickly on any type of standard equipment without the necessity of changeover. It has been woven on both broad and narrow looms, on jacquard looms, on ordinary box looms, on ribbon looms; it has worked successfully on braiders and knitters. Since it is not affected by ordinary changes in temperature, it requires no special treatment or handling. Fabrics made of plastic-coated yarn require no dyeing and no finishing; they are ready to market when they come off the looms.

BONDED WEB FABRICS

In addition to the traditional methods of interlacing yarns to make fabrics, such as weaving, knitting, and lace making, another method is felting. Felt depends upon the interlacing action of wool fibers when formed into a fibrous layer or batt and worked into a compact mass under the influence of moisture and pressure.

The modern counterparts of this type of fabric which make it possible to use fibers lacking the felting properties of wool are bonded webs. These can be made by several methods by which an interlaced mass of fibers in the batt are compressed and bonded together into a sheet or fabric.

The batt may be impregnated with a solution of an adhesive such as a resin, or it may be composed of a mixture of fibers which includes a certain proportion of thermoplastic fibers such as vinyl resin or plasticized cellulose acetate staple fiber. When such a batt is subjected to heat and pressure, the plastic fibers soften and adhere to one another thus entrapping the other fibers and forming a felt-like structure. By varying the amount of plasticized fiber, the types of other fibers used (e.g. cotton, viscose, acetate, wool, etc.) and the temperature, time and pressure to which the batt is subjected, a wide variety of bonded webs can be produced.

These range from very thin filter-like materials such as are used in tea bags, to heavy thick felts or even fibrous tiles.

Masslinn, an adhesive-bonded fabric, is made by Chicopee Manufacturing Company. The cotton comes off the carder in sheets of parallel fibers and is put through rolls which deposit the adhesive in wavy lines on the surface of the cotton. The adhesive takes the place of the cross threads in weaving and reinforces the cotton fibers. It may be of various types, providing wet strength, oil resistance or other desired properties. The resulting fabric is said to be superior to competitive woven goods in absorbency, softness, surface smoothness and draping qualities.

The increased softness and absorbency are the result of bonding only at intervals, which leaves most of the cotton free, in contrast to that which is woven or flattened as in conventional cloth and paper. Thus the same quantity of cotton, which by normal spinning and weaving methods gives a gauzelike mosquito netting, will, by this process, result in a product having approximately the absorbency of a table napkin. The low tensile strength at right angles to the direction of the fibers does not detract from its value in its present applications.

Masslinn is used in disposable diapers and dental towels, and has been suggested for many applications where gauze is now used. It could be utilized for industrial filter cloth or impregnated with synthetic resins to make plastics laminates.

"Webiril" (produced by Kendall Mills) is made by blending heat-softening fibers such as cellulose acetate or vinyl chloride-acetate copolymer, into the cotton web. Under the application of heat and pressure, these combined fibers produce a paper- or felt-like material. This process is flexible so that the weight and properties can be controlled over a wide range by the number of layers and the amount of binder used. For example, a small quantity of thermoplastic binding thread gives a soft, fragile material, while a large quantity imparts density and strength. By varying the proportions of binder fibers and cotton, materials harder and stronger in the center or on one or both surfaces may be obtained. Presence of the thermoplastic binder allows heat

sealing with an ordinary iron, and thus eliminates sewing operations.

Webril is used particularly for heat-sealed tea bags and bags for silica gel.

In a third type of unwoven fabric, the fibers are bonded together by the over-all action of a chemical solution. The resulting product is less absorbent than Masslinn, for example, and is available in weights ranging from 10 to 35 yards per pound. Chemically bonded fabrics have also been used in tea bags and plastics laminates.

Non-woven fabrics have not yet been made strong enough for use in apparel, but continuing research may produce suitable types.

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Plastic-Coated Yarns

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CHAPTER XVIII

Applications and Trade Names

New Fibers Suggested for Various Applications

Awnings

Glass
Vinylidene chloride
Vinyl resin (Vinyon N)

Bathing Suits

Nylon
Rayon
Saponified cellulose acetate
(Fortisan)
Vinyl resin (Vinyon N)

Bedspreads

Glass
Rayon

Belts

Plastic-coated yarn
Vinylidene chloride

Blankets

Casein, soybean protein, or
peanut protein (in blends)
Rayon staple

Bristles

Casein
Cellulose acetate
Nylon
Polyethylene
Saponified cellulose acetate
(Fortisan)
Vinylidene chloride
Vinyl resin

Carpets and Rugs

Nylon staple (in blends)
Rayon staple

Coatings and Suitings

Casein, peanut protein, or soy-
bean protein (in blends)
Nylon staple (in blends)
Rayon staple

Curtains and Draperies

Acetate-coated aluminum
Glass
Nylon
Plastic-coated yarn
Rayon
Vinyl resin (Vinyon)
Vinylidene chloride

Dental Floss

Saponified cellulose acetate
(Fortisan)
Vinyl resin (Vinyon N)

Dress Goods

Casein, peanut protein, or soy-
bean protein (in blends)
Nylon
Rayon
Saponified cellulose acetate
(Fortisan)

Electrical Applications

Glass

New Fibers Suggested for Various Applications—Continued

<i>Electrical Applications—Continued</i>	Saponified cellulose acetate (Fortisan)
Nylon	Vinyl resin (Vinyon)
Polyethylene	<i>Handbags</i>
Saponified cellulose acetate (Fortisan)	Acetate-coated aluminum
Vinyl resin (Vinyon N)	Cellulose acetate butyrate
<i>Felted Goods</i>	Plastic-coated yarn
Casein, peanut protein, or soy-bean protein	Rayon
Nylon	Vinyl resin (Vinyon)
Polyethylene	Vinylidene chloride
Polystyrene (Polyfibre)	<i>Heat-Resistant Fabrics</i>
Vinyl resin	Glass
<i>Filling and Stuffing Materials</i>	Tetrafluoroethylene
Casein, peanut protein, or soy-bean protein	<i>Hose</i>
Cattail floss	High-pressure:
Glass	Saponified cellulose acetate (Fortisan)
Hollow cellulosic filaments (Bubblfil)	Chemical-resistant:
Milkweed floss	Vinyl resin (Vinyon N)
Polystyrene (Polyfibre)	<i>Hosiery</i>
Rayon staple	Nylon
<i>Filter Fabrics</i>	Rayon
Glass	Saponified cellulose acetate (Fortisan)
Nylon	Vinyl resin (Vinyon N)
Polyethylene	Vinylidene chloride
Rayon (high-tenacity)	Viscose rayon (high-tenacity)
Stainless steel	<i>Knitted Undergarments</i>
Vinyl resin (Vinyon)	Nylon
Vinylidene chloride	Rayon
<i>Fishing Lines and Nets</i>	Saponified cellulose acetate (Fortisan)
Nylon	<i>Lampshades</i>
Polyethylene	Glass
Saponified cellulose acetate (Fortisan)	Nylon
Vinyl resin (Vinyon N)	Rayon
Vinylidene chloride	<i>Luggage</i>
<i>Foundation Garments</i>	Glass
Nylon	Plastic-coated yarn
Rayon	Vinylidene chloride

*New Fibers Suggested for Various Applications—Continued**Mechanical Packing*

Rayon tow

Vinyl resin

Millinery

Plastic-coated yarn

Rayon

Vinylidene chloride

*Neckties*Casein, peanut protein, or soy-
bean protein (in blends)

Nylon

Rayon

Parachutes

Nylon

Saponified cellulose acetate
(Fortisan)*Plastics Reinforcement*

Glass

Polystyrene (Polyfibre)

Saponified cellulose acetate
(Fortisan)*Rainwear*

Nylon

Rayon (high-tenacity)

Saponified cellulose acetate
(Fortisan)

Vinyl resin (Vinyon)

*Robes*Casein, peanut protein, or soy-
bean protein (in blends)

Rayon staple

Rope, Cord, Tape, etc.

Nylon

Polyethylene

Saponified cellulose acetate
(Fortisan)

Vinyl resin

Vinylidene chloride

*Sail Cloth*Saponified cellulose acetate
(Fortisan)

Viscose rayon (high-tenacity)

Vinyl resin (Vinyon N)

Screening

Glass

Nylon

Plastic-coated yarn

Polyethylene

Saponified cellulose acetate
(Fortisan)

Vinyl resin

Vinylidene chloride

Sewing Thread

Glass

Nylon

Saponified cellulose acetate
(Fortisan)

Vinyl resin (Vinyon N)

Shirtings

Nylon

Rayon (high-tenacity)

Saponified cellulose acetate
(Fortisan)*Shoe Fabrics*

Acetate-coated aluminum

Cellulose acetate butyrate

Nylon

Plastic-coated yarn

Rayon

Vinyl resin (Vinyon N)

Vinylidene chloride

Shower Curtains

Glass

Nylon

Rayon

Vinyl resin (Vinyon)

*Sportswear*Casein, peanut protein, or soy-
bean protein (in blends)

Nylon staple

Rayon staple

*New Fibers Suggested for Various Applications—Continued**Surgical Sutures*

Nylon
 Polyethylene
 Polyvinyl alcohol
 Vinyl resin (Vinyon N)

Sweaters

Casein, peanut protein, or soy-
 bean protein (in blends)
 Nylon staple
 Rayon staple

Tablecloths and Mats

Glass
 Plastic-coated yarn
 Rayon
 Vinylidene chloride

Tent Fabrics

Nylon
 Saponified cellulose acetate
 (Fortisan)
 Vinyl resin (Vinyon N)

Tire Cords

Nylon
 Viscose rayon (high-tenacity)

Towels

Viscose rayon staple

Umbrella Fabrics

Nylon
 Rayon
 Saponified cellulose acetate
 (Fortisan)
 Vinyl resin (Vinyon N)

Upholstery

Cellulose acetate butyrate
 Nylon
 Plastic-coated yarn
 Rayon
 Vinyl resin
 Vinylidene chloride

Wearing Apparel Accessories

Acetate-coated aluminum
 Aluminum yarn
 Cellulose acetate butyrate
 Plastic-coated yarn
 Rayon
 Vinylidene chloride
 Vinyl resin

Fiber Trade Names Index

<i>Trade name</i>	<i>Type of material</i>	<i>Manufacturer</i>
Acele	Acetate rayon yarn and staple fiber	E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.
Aralac	Casein fiber	Aralac, Inc. (Div. of National Dairy Products Corp.), New York, N. Y.
Ardil	Peanut protein fiber	Imperial Chemical Industries Ltd., London, England
Asbeston	Fine asbestos-cotton yarn	United States Rubber Co., New York, N. Y.
Avisco	High-strength viscose rayon staple	American Viscose Corp., Wilmington, Del.
Belastraw	Viscose straw yarn	Hartford Rayon Corp., Rocky Hill, Conn.
Bemberg	Cuprammonium rayon	American Bemberg Corp., New York, N. Y.
Briglo	Bright viscose rayon	American Enka Corp., New York, N. Y.
Celafibre	Acetate staple fiber	British Celanese Ltd., London, England
Celafil	Acetate worsted-like yarn	Celanese Corp. of America, New York, N. Y.
Celairese	Acetate staple fiber	Celanese Corp. of America, New York, N. Y.
Celanese	Cellulose acetate yarn	Celanese Corp. of America, New York, N. Y.
Celawol	Acetate and wool, staple or continuous filament	Celanese Corp. of America, New York, N. Y.
Chalkelle	Dull viscose rayon yarn	American Viscose Corp., Wilmington, Del.
Chardonize	Dull viscose rayon yarn	Celanese Corp. of America, New York, N. Y.
Contro	Elastic yarn (synthetic or natural rubber)	Firestone Rubber and Latex Products Co. (Div. of Firestone Tire & Rubber Co.), Fall River, Mass.
Cordura	High-tenacity viscose tire yarn	E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.
Delray	Viscose rayon yarn	Delaware Rayon Co., New Castle, Del.
Delvisca	Viscose straw yarn	Delaware Rayon Co., New Castle, Del.
Dulesco	Semi-dull viscose rayon yarn	American Viscose Corp., Wilmington, Del.
Dul-Tone	Dull viscose rayon yarn and circular knitted rayon fabrics	Industrial Rayon Corp., Cleveland, Ohio
Englo	Dull viscose rayon yarn	American Enka Corp., New York, N. Y.
Fiberglas	Glass fiber	Owens-Corning Fiberglas Corp., Toledo, Ohio

Fiber Trade Names Index—Continued

<i>Trade name</i>	<i>Type of material</i>	<i>Manufacturer</i>
Fibro	Rayon staple fiber	American Viscose Corp., Wilmington, Del.
Fortisan	Saponified cellulose acetate yarn	Celanese Corp. of America, New York, N. Y.
High-Narco	Medium high-tenacity viscose rayon yarn	North American Rayon Corp., New York, N. Y.
Hygram	Semi-high-tenacity viscose rayon yarn	Celanese Corp. of America, New York, N. Y.
Koda	Acetate filament yarn	Tennessee Eastman Corp., Kingsport, Tenn.
Kohorn	Viscose wool-type staple fiber	Oscar Kohorn & Co., Ltd., New York, N. Y.
Lanese	Acetate staple and spun yarns	Celanese Corp. of America, New York, N. Y.
Lanital	Name of first casein fiber produced commercially	Snia Viscosa, Italy
Lastex	Elastic yarn (natural or synthetic rubber)	United States Rubber Co., New York, N. Y.
Laton	Fine elastic yarn (natural or synthetic rubber)	United States Rubber Co., New York, N. Y.
Lumite	Vinylidene chloride copolymer screen material	Chicopee Manufacturing Corp., New York, N. Y.
Matesa	Dull cuprammonium rayon yarn	American Bemberg Corp., New York, N. Y.
Narco	Regular strength viscose rayon yarn	North American Rayon Corp., New York, N. Y.
Newbray	Bright viscose rayon yarn	New Bedford Rayon Co., New Bedford, Mass.
Newdull	Dull viscose rayon yarn	New Bedford Rayon Co., New Bedford, Mass.
Newlow	Semi-dull viscose rayon yarn	New Bedford Rayon Co., New Bedford, Mass.
Nylon	Polyamide	E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.
Palconia	Redwood bark fiber	The Pacific Lumber Co., San Francisco, Calif.
Perlglo	Semi-dull viscose rayon yarn	American Enka Corp., New York, N. Y.
Plexon	Plastic-coated yarn	Freydberg Bros.-Strauss, Inc., New York, N. Y.
Polyfibre	Polystyrene fiber	The Dow Chemical Co., Midland, Mich.
Premier	Bright viscose rayon yarn and circular knitted fabrics	Industrial Rayon Corp., Cleveland, Ohio
Rayflex	High-tenacity viscose rayon tire yarn	American Viscose Corp., Wilmington, Del.
Reymet	Flat aluminum yarn	Reynolds Metals Co., Richmond, Va.

Fiber Trade Names Index—Continued

<i>Trade name</i>	<i>Type of material</i>	<i>Manufacturer</i>
Reyspun	Aluminum-covered yarn	Reynolds Metals Co., Richmond, Va.
Saran	Vinylidene chloride copolymer	The Dow Chemical Co., Midland, Mich.
Semi-Dul	Partially pigmented viscose rayon yarn	North American Rayon Corp., New York, N. Y.
Seraceta	Acetate rayon yarn and staple fiber	American Viscose Corp., Wilmington, Del.
Spun-Black	Black viscose rayon yarn	Industrial Rayon Corp., Cleveland, Ohio
Spun-Lo	Viscose rayon yarn and circular knitted fabrics	Industrial Rayon Corp., Cleveland, Ohio
Super-Narco	High-tenacity viscose rayon yarn	North American Rayon Corp., New York, N. Y.
Teca	Crimped acetate rayon staple fiber	Tennessee Eastman Corp., Kingsport, Tenn.
Tempra	High-tenacity viscose rayon tire yarn	American Enka Corp., New York, N. Y.
Tenasco	High-tenacity viscose rayon yarn	American Viscose Corp., Wilmington, Del.
Tenasco M	Medium high-tenacity viscose rayon yarn	American Viscose Corp., Wilmington, Del.
Tufton	Viscose rayon staple fiber for carpets	American Viscose Corp., Wilmington, Del.
Typha	Cattail floss fiber	Burgess-Manning Co., Chicago, Ill.
Tyron	High-tenacity viscose rayon tire cord yarn and fabrics	Industrial Rayon Corp., Cleveland, Ohio
Velon	Vinylidene chloride copolymer	Firestone Tire & Rubber Co., Akron, Ohio
Veri-Dul	Dull viscose rayon yarn	Skenandoa Rayon Corp., Utica, New York
Vinyon	Vinyl chloride-vinyl acetate copolymer yarn	American Viscose Corp., Wilmington, Del.
Vinyon E (discontinued)	Plasticized vinyl copolymer elastic yarn	American Viscose Corp., Wilmington, Del.
Vinyon N	Vinyl chloride-acrylonitrile copolymer yarn	American Viscose Corp., Wilmington, Del.
Vinyon HH	Vinyon staple fiber with low fusing point	American Viscose Corp., Wilmington, Del.
Vinyon HST	High-stretched, low-elongation Vinyon yarn	American Viscose Corp., Wilmington, Del.
Vinyon ST	Medium-stretched Vinyon yarn	American Viscose Corp., Wilmington, Del.
Vinyon UST	Unstretched, low-tenacity, high-elongation Vinyon yarn	American Viscose Corp., Wilmington, Del.
Xtra-Dul	Pigmented viscose rayon yarn	North American Rayon Corp., New York, N. Y.

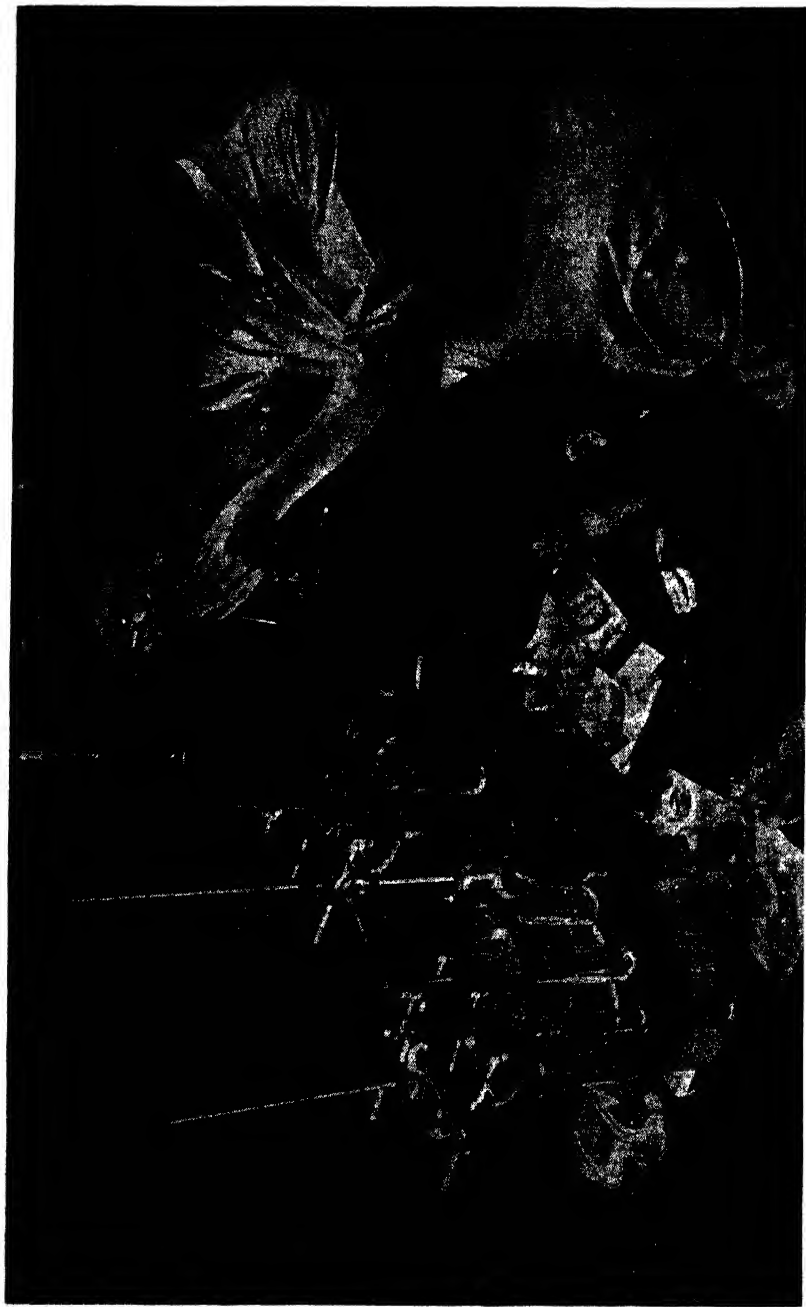


FIG. 81. The chemical laboratory is the birthplace of synthetic fibers, and many new types will undoubtedly be developed in the future.

Courtesy Celanese Corporation of America

CHAPTER XIX

Research and The Future of Fibers

SUMMARY

The broad pattern of trends in the use of fibers is evident from an analysis of production and price data over a period of years. Rayon has gained rapidly in importance, whereas cotton and wool have shown declining tendencies. Silk has lost a large part of its former markets.

However, cotton still accounts for the great bulk of textile fiber consumption. The very size and diversity of its markets, as well as its relatively low price, serve to protect it from any serious inroads by the manufactured fibers, at least for many years to come. Wool, because of its much smaller volume of consumption and higher price, is in a somewhat more vulnerable competitive position.

Perhaps the most important factor in determining fiber trends is research. Rayon has had a long history of research and this helps to explain its growth compared with the natural fibers. But cotton and wool are beginning to benefit from research undertaken by governmental and private organizations.

The new synthetic fibers are all sponsored by companies noted for their research policies and should undergo continuous improvement in properties and reduction in prices. Although consumption of these fibers is as yet small relative to the industry total, they may be expected to show the most rapid growth.

RESEARCH

The introduction of a number of new types of fibers within recent years has made the entire textile industry research-con-

scious. Up until recent years, the textile industry as a whole had lagged considerably behind most other basic industries in the application of science to the development of new and improved products and processes. But there are many indications that the industry has awakened to the possibilities of research.

What research can accomplish in the development of new types of fibers is evident from the history of rayon. When rayon was first introduced, it was so inferior in quality and high in price compared with the rayon of today, that it is difficult to see how it could have survived. Indeed, it was regarded as a cheap substitute for silk and about the only points it had in its favor were lustrous appearance and the fact that it took dyes beautifully. Over a period of years, the quality of rayon has been gradually improved and its price lowered with the result that the rayon of today is an entirely different material from that of thirty years ago.

Rayon was improved and its competitive position strengthened relative to other fibers because more research effort was expended on it than on other fibers. This is evident from the following tabulation showing the number of industrial research laboratories in the United States engaged in research on some of the more important fibers in 1940:

Rayon	24
Cotton	13
Wool	14
Silk	9
Flax	1

Source: "Industrial Research Laboratories of the United States," *Bulletin Number 104*, National Research Council, December 1940.

Like rayon, the synthetic fibers introduced during the past 10 years were all created by research and should continue to benefit from well-organized research programs of their sponsors. All the synthetic fibers are in an early stage of commercial development and should undergo steady improvement in properties and reduction in costs of production at least for many years to come.

Fibers can be made from an almost endless variety of synthetic materials, as well as from plant and animal proteins, cellulose derivatives and the like. Many new fiber-forming materials are still in the laboratory and others remain to be discovered. The future should witness a continuous procession of new fibers from the laboratory, to the pilot plant and thence into commercial production.

The development of the manufactured fibers has resulted not only in an intensification of research to find new fibers, but has forced those who are economically dependent upon the natural fibers to embark upon research programs in order to maintain their competitive positions.

Through numerous research programs of the Federal and State Governments and various private agencies, firms, and individuals in the Cotton Belt, much has been done in recent years to strengthen the competitive position of cotton and to make cotton growing more profitable to domestic farmers. These accomplishments involve soil conservation and soil building activities; farm management practices; varietal development; methods of controlling insects and diseases; ginning, packaging, and marketing facilities and methods; and the development and promotion of new and expanded uses for cotton.

Largely as a result of these developments, the yield per acre in 1940-1944 averaged 50% higher than in 1928-1932, the man-hours of labor required to produce a given quantity of cotton have been greatly reduced, ginning services have been materially improved, the staple length of the crop has increased, and new uses and new methods of processing raw cotton and of treating cotton fabrics have been developed. Furthermore, a program was recently inaugurated for making cotton available in foreign markets at competitive world prices. Nevertheless, it is apparent that even more aggressive efforts along these and other lines are necessary if cotton is to hold anything like its present position among the apparel fibers.

In the cases of both the manufactured and the natural fibers, research is proceeding in many directions. Every fiber is capable

of further improvement and none has yet attained its maximum degree of usefulness. For every fiber, the field of *potential* applications is greater than that of *established* applications and research men are constantly striving to extend the latter.

TABLE 19. 1. FIBERS UNDER INVESTIGATION BY REGIONAL RESEARCH LABORATORIES OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

Eastern Regional Research Laboratory, Philadelphia, Pa.
Casein

Northern Regional Research Laboratory, Peoria, Illinois
Soybean protein
Zein (corn protein)
Amylose acetate

Southern Regional Research Laboratory, New Orleans, La.
Cotton
Peanut protein

Western Regional Research Laboratory, Albany, Calif.
Chicken feathers (keratin)
Egg albumin
Wheat protein

Here are some of the things research men have been trying to do:

1. Develop entirely new types of synthetic fibers.
2. Improve the dyeing properties of the established synthetic fibers and also develop better methods of dyeing them.
3. Develop protein fibers that are as good or better than wool.
4. Increase the resistance of wool to shrinkage, moths, etc.
5. Put a crimp in rayon staple fiber and otherwise enhance its wool-like properties.
6. Increase the strength of protein and cellulosic fibers by incorporating synthetic resins in the spinning solutions before extrusion into filaments.

7. Increase the wet strength of rayon, as well as its dry strength.
8. Increase the tensile strength of cotton and wool.
9. Make glass fiber suitable for use in wearing apparel.
10. Make irregularly shaped cross sections of certain manufactured fibers circular in shape.
11. Make multifilaments from synthetics in cases where monofilaments are now produced.

COMPETITION AMONG THE FIBERS

Before considering the question of present and future competition among the various fibers, it may be helpful to review briefly the general background of fiber consumption in the United States.

Table 19.7 shows the per capita consumption for the four principal textile fibers—cotton, wool, silk, and rayon—since 1911. Data are also presented showing per capita consumption by decades.

The first interesting fact which emerges is that the total per capita consumption for these fibers, which account for the great bulk of all the fibers used, has not shown much change. For the decade 1931-1940, it averaged 30.8 lbs., compared with 30.4 lbs. for the 1921-1930 decade, and 31.4 lbs. for 1911-1920.

This may seem startling in view of the trend toward higher living standards and new industrial uses developed for fibers, but it is a fundamental fact that should be kept in mind in considering the effects of competition. Apparently, increased consumption of fibers for industrial purposes has been offset largely by decreased use for apparel resulting from the trend toward lightweight clothing.

Of course, per capita consumption of textile fibers has varied considerably from year to year. People often defer purchases of clothing in years of depression or when there is a scarcity of materials, and they tend to over-buy when conditions are prosperous. But the rate of use, or wear, seems to be relatively constant, and over a period as long as ten years, excess and deficient purchases appear to cancel out.

The result is that, although per capita consumption of textile fibers has varied considerably from year to year, it has been remarkably stable from decade to decade. The significance of this lies in the fact that competitive gains for one fiber over a period of years are usually offset by losses of another (or others). Thus, per capita consumption of rayon increased more than 2 lbs. between the decades 1911-1920 and 1931-1940, but cotton showed a corresponding decline. The introduction of nylon in 1939 was followed by a decline in silk consumption in 1940, principally in the women's hosiery field.

On a per capita basis, cotton, wool and silk have shown declining tendencies. Per capita consumption of cotton declined from 27.9 lbs. in 1911-1920, to 26.1 lbs. in 1921-1930, and to 25.4 lbs. in 1931-1940.

Per capita consumption of wool averaged 3.08 lbs. annually in 1911-1920, fell slightly to 3.04 lbs. in 1921-1930, and then to 2.64 lbs. in 1931-1940.

Annual average per capita consumption of silk was 0.38 lb. in 1911-1920, then it rose to 0.63 lb. in 1921-1930, and fell to 0.52 lb. in 1931-1940.

As contrasted with the natural fibers, rayon has shown a continuous growth over a period of years. Annual average per capita consumption of rayon was 0.06 lb. in 1911-1920, rose to 0.58 lb. in 1921-1930, and then to 2.25 lb. in 1931-1940. Since then there has been a further sharp rise in the use of rayon.

Comparison of the four principal textile fibers may be made also on a percentage basis. In Table 19.5, the total consumption each year for the four fibers is taken as 100%.

Cotton declined from 88.9% of the total in 1920 to 78.3% in 1944. Wool showed little change as a proportion of the total; it was 9.9% in 1920 and 10.2% in 1944. Silk was 0.9% in 1920, rose to 2.5% in 1930, and then fell off to negligible proportions during the war. Rayon increased from 0.3% in 1920 to 11.5% in 1944.

In 1944, the distribution was: cotton, 78.3%, wool, 10.2%; and rayon, 11.5%.

In general, cotton still accounts for nearly 80% of total fiber consumption, while wool and rayon each account for about 10%. In other words, about 90% of all the fibers used are natural fibers, while the synthetics and semi-synthetics make up only about 10% of the total. The consumption of the new synthetic fibers in 1944 was of negligible proportions.

With further growth in the use of rayon and the attainment of commercial volume by the new synthetics, it is reasonable to expect that the manufactured fibers will rise gradually far above the present 10%.

Therefore, as the new fibers increase in importance, some decline may be expected in the older fibers. The result may well be a sharply lower level of consumption of silk, if it does not disappear from the American market. The decline in importance of cotton and wool no doubt will be a slower process.

In appraising the effects of competition on the natural fibers, a number of factors should be considered. Among these are volume of production, relative prices, and diversity of markets.

One factor that serves to protect the position of cotton is the vast size of its markets. It is difficult to conceive of any new fiber coming into use rapidly enough to make any serious inroads into cotton for many years to come, simply because no competing material could be produced in large enough volume to take its place. Cotton consumption in recent years has aggregated around 5 billion lbs. annually, truly a vast figure! Even if we assume that some other fiber were developed that proved to be both better and cheaper than cotton (and that is quite an assumption!), it would be many years, to say the least before it could be produced in comparable volume. Expansion in productive facilities, distribution channels, and the like, as well as adaptation to new markets, take considerable time. Then there is the factor of human inertia which must be overcome before a new material

is used in place of an old one. In short, cotton's best protection is the huge size of its markets.

Closely related to volume of output is diversity of markets. It is axiomatic that the more uses a material has, the more difficult it is to displace. While a new material may prove better or cheaper in certain applications than an older one, it is highly improbable that it will prove more satisfactory in *all* applications. The present applications of cotton and wool are too numerous to mention. Therefore, the chances of any new fiber or combination of fibers proving more satisfactory in all of their markets are negligible. Any displacement of these fibers will be a gradual process.

This is not true, however, in the case of silk. Not only has silk been used in relatively small quantities, but its applications have been rather specialized. A luxury product, it has been used principally in women's hosiery, dress goods, and specialties.

This brings us to a discussion of general-purpose and special-purpose fibers. Cotton and wool are general-purpose fibers; whereas silk is a special-purpose fiber. It is obvious that the older general purpose fibers can be threatened only by new general-purpose fibers. On the other hand, an established special-purpose fiber, like silk, can easily be displaced.

From a competitive standpoint, the only new fibers that will constitute a serious competitive threat to cotton, wool, and rayon, are general-purpose fibers. All the new synthetic fibers are thus far in the special-purpose class. The special-purpose fibers may displace the general-purpose fibers in certain applications without affecting their markets as a whole.

One of the most important of all factors is price. It is obvious that superiority in properties alone is not enough. The new material must excel the older one to a great enough extent to warrant a higher price; or else it must be cheaper.

It is reasonable to expect that as volume of production of the new fibers increases, their prices will decline. Further research

and development should uncover new sources of raw materials and new processes of production, all of which will tend to lower costs.

INCIDENCE OF COMPETITION

One of the most important questions arising from competition among the various fibers is—who will be affected by any displacement which may occur? This question is of vital interest to the millions of people deriving a livelihood from the textile business in all its ramifications.

In general, there are two distinct groups—the producers of the basic materials or fibers and the processors. The former would include the cotton farmer, wool grower, and the chemical industry. The latter, would include the textile industry.

The basic competition is one between material producers and any displacement of one fiber by another will therefore fall upon the original producer. This may be the cotton farmer in the South, the wool grower in Australia, or the silk producer in the Far East.

As far as the textile industry is concerned, it can use one fiber as readily as another. One reason rayon staple fiber has gained such wide acceptance is that it can be spun into yarns on the cotton, woolen, or worsted spinning machinery. The textile industry, therefore, should not be affected to any important extent by the substitution of new fibers for the established fibers.

Eventually, the economic repercussions of the battle of fibers may be world wide. Large areas of the world have been dependent to a major or minor extent upon the production of cotton, wool and silk. The effects of any large scale displacement of these fibers undoubtedly would be serious.

Except in the case of silk, however, any displacement is likely to be a gradual one. It is generally believed in the industry that silk may be able to hold only about one third of its prewar markets in the United States. This would indicate a reduction in annual

consumption from around 50 million lbs. to about 15 million lbs. The Far East would logically be the first area to feel the effects of any displacement of natural fibers.

Since cotton and wool probably will lose ground at a much slower rate, the effects on other fiber-producing areas of the world should be gradual. In the meantime, further improvements in cotton and wool, resulting from new chemical treatments, cheaper methods of production, and the like, may enable these fibers to hold most of their present markets.

The United States, as a leading cotton-producing nation, is in a rather fortunate position, since cotton is by far the dominant fiber, and it would take many years for it to suffer any serious displacement. Our domestic wool industry, because it is relatively much smaller than cotton and dependent upon tariff protection, is in a somewhat more vulnerable position.

It would be a mistake, however, to look upon our textile industry from a purely nationalistic standpoint, for essentially, it is part of a new world economy. In the final analysis, we cannot reduce purchasing power in any part of the world without affecting our own export markets and eventually, perhaps, threatening our own security. In the past, we have imported silk and exported cotton. Our national prosperity is dependent to a considerable extent upon our maintaining the purchasing power of foreign nations as well as our own.

It would, therefore, be fallacious to assume that we can substitute domestically produced synthetic materials for natural materials, formerly imported on a large scale, without sooner or later causing serious dislocations in the delicate balance of world trade.

The ultimate results may well be that each nation will tend to become more self-sufficient with regard to textiles. The production of synthetic fibers, unlike that of natural fibers, will not be localized but will become world wide. Certain areas are better adapted than others for growing cotton, wool, or silk, but there is no monopoly on chemical raw materials.

TABLE 19.2. COTTON'S COMPETITORS *

<i>Natural fibers</i>	<i>Manufactured fibers</i>	<i>Non-textile items</i>
Jute	Rayon, filament yarn, staple	Paper
Hard fibers	Nylon	Wood
Silk	Saran, Velon	Metals
Flax	Vinyon	
Wool	Protein	
	Glass	

* Source: "Shall Post-War Markets for Cotton Textiles Expand or Contract?" The Association of Cotton Textile Merchants of New York, December 1944.

TABLE 19.3. PRINCIPAL USES OF COTTON GOODS NOTED AGAINST THE ACTUAL OR POTENTIAL SOURCES OF COMPETITION *

LEADING APPAREL USES †

<i>Use</i>	<i>Cotton consumed (thousands of bales)</i>	<i>Competition</i>
Shirts	464	Moderate: rayons, especially sportswear
Piece goods	332	Considerable: rayons, synthetics
Trousers	285	Considerable: rayons, blends
Men's overalls	232	Negligible
Men's underwear	210	Moderate: rayons
Women's dresses	175	Considerable: rayons, synthetics
Women's underwear	104	Considerable: rayons, synthetics
Men's hosiery	98	Considerable: rayons, wools
Men's nightwear	75	Moderate: rayons
Men's work gloves	62	Negligible

* Source: "Shall Post-War Markets for Cotton Textiles Expand or Contract?" The Association of Cotton Textile Merchants of New York, December 1944.

† End uses and cotton consumption based on data of the last peacetime year 1939 from the National Cotton Council. In summary, the ten items listed under apparel total 2,037,000 bales, or 74.6% of all 1939 consumption of 2,731,000 in the apparel field. The items facing negligible and moderate competition combined total to 1,043,000 bales, or 51.2% of the ten items. Serious competition is faced by 48.8%.

TABLE 19.3—Continued

LEADING HOUSEHOLD USES ‡

Sheets	433	Negligible
Towels	303	Considerable: paper
Blankets	180	Considerable: wool, rayon, blends
Drapery, upholstery	151	Considerable: rayon, synthetics, glass fiber and jute
Rugs, carpets	149	Considerable: flax, jute, paper, others
Curtains	130	Considerable: rayons, synthetics
Bedspreads	94	Moderate: rayons
Pillowcases	75	Negligible
Bed tickings	73	Negligible
Oil cloths	63	Negligible

‡ In summary, the ten household items account for 1,654,000 bales, or 91.5% of all 1939 household goods consumption of 1,808,000 bales. The combined total of items of negligible and moderate competition is 738,000 bales, or 44.6% of the ten classes; serious competition is faced by 55.4%.

LEADING INDUSTRIAL USES §

Automobiles	707	Considerable: high-tenacity rayon, synthetics
Bags	473	Considerable: burlap, paper
Cordage, twine	248	Considerable: jute, hemp, sisal, syn- thetics
Laundry	131	Negligible
Shoes	128	Negligible
Thread	120	Considerable: flax, silk, synthetics
Electric insulation	83	Considerable: glass fiber, silk
Artificial leather	63	Negligible
Belts (machinery)	61	Considerable: leather
Hose	40	Considerable: flax

§ In summary, the ten industrial items total 2,054,000 bales, or 76.6% of the 2,677,000 total use in 1939 for industrial purposes. Total of negligible and moderate competition items is 322,000 bales, or 15.7% of the ten classes. Facing serious competition are 84.3%. The total of cotton consumed in the thirty uses above in 1939 is 5,745,000 bales, or 78.0% of the total market that year of 7,369,000 bales. Of this figure, items classed as faced with negligible competition amount to 1,260,000 bales, or 21.9%, moderate 843,000 bales, or 14.7%, and considerable competition 3,642,000 bales, or 63.4%.

TABLE 19.4. CONSUMPTION OF FIBERS IN THE UNITED STATES *
(Millions of Pounds)

Year	Cotton †	Wool ‡	Rayon §	Silk ||	Total
1945	4508	648	768	Nominal	5924
1944	4788	624	705	Nominal	6116
1943	5269	628	656	Nominal	6553
1942	5637	614	621	Nominal	6872
1941	5187	652	592	25	6456
1940	3954	411	482	36	4883
1939	3630	396	459	47	4532
1938	2919	284	329	52	3584
1937	3657	381	305	51	4397
1936	3470	406	322	58	4256
1935	2755	417	259	62	3493
1934	2655	230	197	58	3140
1933	3052	317	217	60	3646
1932	2463	230	155	71	2919
1931	2657	311	159	77	3204
1930	2611	263	119	76	3069
1929	3423	368	133	81	4005
1928	3184	333	101	74	3692
1927	3588	354	100	72	4114
1926	3215	343	61	66	3685
1925	3075	350	58	66	3549
1924	2637	342	42	48	3069
1923	3120	422	33	47	3622
1922	2910	406	25	48	3389
1921	2595	343	20	42	3000
1920	2828	314	9	29	3180

* Source: *Rayon Organon*.

† Cotton: (a) Bales consumption for 100% of the industry, from U. S. Dept. of Commerce; (b) average weight of bales consumed, from U. S. Dept. of Commerce, "Cotton Production and Distribution," where weight of bales in calendar year is assumed to average the weight of the current and the past year's crop-year bales; (c) consumption of cotton then is (a) \times (b).

‡ Wool: Total pounds consumption, scoured basis, from U. S. Dept. of Commerce, Bureau of the Census. All data in this series have been inflated to a 100% sample.

§ Rayon: Data include both rayon yarn and rayon staple fiber deliveries to domestic consumers plus rayon imports for consumption.

|| Silk: (a) Silk deliveries to American mills in bales, by the Commodity Exchange, Inc., less silk re-exports from the United States, represents silk consumption closely on an annual basis, manufacturers' stocks varying but slightly percentagewise to the deliveries; (b) the average weight of a silk bale is assumed to be 132 $\frac{1}{4}$ lbs., and average boil-off of 19% (18% to 24%) is assumed to be equally off-set by subsequent weighting; (c) consumption of silk in pounds, therefore, is (a) \times (b).

TABLE 19.5. ANNUAL FIBER CONSUMPTION IN THE UNITED STATES *
(Total for Cotton, Wool, Rayon, and Silk = 100%)

<i>Year</i>	<i>Cotton (%)</i>	<i>Wool (%)</i>	<i>Rayon (%)</i>	<i>Silk (%)</i>
1945	76.1	10.9	13.0	...
1944	78.3	10.2	11.5	...
1943	80.4	9.6	10.0	...
1942	82.0	8.9	9.1	...
1941	80.3	10.1	9.2	0.4
1940	81.0	8.4	9.9	0.7
1939	80.1	8.8	10.1	1.0
1938	81.4	7.9	9.2	1.5
1937	83.2	8.7	6.9	1.2
1936	81.5	9.5	7.6	1.4
1935	78.9	11.9	7.4	1.8
1934	84.5	7.3	6.3	1.9
1933	83.7	8.7	6.0	1.6
1932	84.4	7.9	5.3	2.4
1931	82.9	9.7	5.0	2.4
1930	85.0	8.6	3.9	2.5
1929	85.5	9.2	3.3	2.0
1928	86.3	9.0	2.7	2.0
1927	87.2	8.6	2.4	1.8
1926	87.3	9.3	1.6	1.8
1925	86.6	9.9	1.6	1.9
1924	85.8	11.2	1.4	1.6
1923	86.1	11.7	0.9	1.3
1922	85.9	12.0	0.7	1.4
1921	86.5	11.4	0.7	1.4
1920	88.9	9.9	0.3	0.9

* Source: *Rayon Organon*.

TABLE 19.6. PER CAPITA CONSUMPTION (IN POUNDS) OF FIBERS
IN THE UNITED STATES *

<i>Annual average</i>	<i>Cotton</i>	<i>Wool</i>	<i>Silk</i>	<i>Rayon</i>	<i>Total</i>
1940-31	25.4	2.64	0.52	2.25	30.8
1930-21	26.1	3.04	0.63	0.58	30.4
1920-11	27.9	3.08	0.38	0.06	31.4

* Source: Bureau of Agricultural Economics, U. S. Dept. of Agriculture.

TABLE 19.7. ANNUAL PER CAPITA CONSUMPTION (IN POUNDS) OF FIBERS IN THE UNITED STATES *

<i>Year</i>	<i>Cotton †</i>	<i>Wool ‡</i>	<i>Silk §</i>	<i>Rayon ||</i>
1945	32.2	4.59	....	5.46
1944	34.5	4.48	....	5.07
1943	35.5	4.54	....	4.78
1942	40.2	4.54	....	4.58
1941	40.7	4.83	0.19	4.41
1940	35.7	3.07	0.36	3.63
1939	29.0	3.01	0.42	3.48
1938	25.7	2.18	0.44	2.52
1937	21.9	2.94	0.49	2.35
1936	30.0	3.15	0.52	2.50
1935	24.1	3.26	0.57	2.02
1934	20.4	1.81	0.48	1.55
1933	22.2	2.51	0.56	1.72
1932	23.8	1.83	0.60	1.24
1931	19.1	2.49	0.70	1.27
1930	20.5	2.13	0.65	0.96
1929	24.3	3.02	0.80	1.10
1928	28.3	2.76	0.72	0.83
1927	27.6	2.97	0.71	0.84
1926	29.4	2.92	0.65	0.52
1925	26.4	3.02	0.66	0.50
1924	25.7	3.00	0.52	0.37
1923	23.9	3.77	0.55	0.29
1922	28.8	3.69	0.52	0.22
1921	25.7	3.16	0.48	0.18
1920	22.0	2.95	0.36	0.08
1919	29.3	3.13	0.52	0.09
1918	26.6	3.82	0.46	0.06
1917	30.3	3.33	0.42	0.07
1916	31.8	3.55	0.40	0.06
1915	30.6	3.35	0.37	0.06
1914	27.2	2.74	0.31	0.05
1913	27.5	2.35	0.35	0.04
1912	27.7	2.92	0.31	0.03
1911	26.2	2.64	0.28	0.02

* Source: Bureau of Agricultural Economics, U. S. Dept. of Agriculture. Calendar-year figures divided by July 1st population estimates to get per capita figures. Crop-year figures (for cotton) divided by January 1st population estimates to get per capita figures.

† 1945 and 1944 calendar years; years beginning August 1, 1914 to 1943; years beginning September 1, 1911-1913.

‡ Apparel and carpet wool, reduced to scoured basis; on calendar-year basis.

§ Net imports, 1911-1933; imports for consumption, 1934 to date, on calendar-year basis.

|| From *Rayon Organon*. Includes filament yarn and staple fiber; calendar-year basis.

TABLE 19.8. TOTAL MILL CONSUMPTION OF RAW FIBERS
IN THE UNITED STATES *

<i>Period †</i>	<i>Cotton</i>	<i>Wool</i>	<i>All others ‡</i>	<i>Total</i>
MILLIONS OF POUNDS				
1940-43	5150	563	1323	7036
1935-39	3409	377	972	4758
1930-34	2687	285	730	3702
1925-29	3292	365	848	4505
1920-24	2821	378	751	3950
1915-19	2974	386	908	4268
1910-14	2446	297	796	3540
PERCENTAGES				
1940-43	73.2	8.0	18.8	100.0
1935-39	71.7	7.9	20.4	100.0
1930-34	72.6	7.7	19.7	100.0
1925-29	73.1	8.1	18.8	100.0
1920-24	71.4	9.6	19.0	100.0
1915-19	69.7	9.0	21.3	100.0
1910-14	69.1	8.4	22.5	100.0
PER CAPITA (IN POUNDS)				
1940-43	38.4	4.2	9.9	52.5
1935-39	26.4	2.9	7.5	36.9
1930-34	21.5	2.3	5.8	29.7
1925-29	27.9	3.1	7.2	38.1
1920-24	25.7	3.4	6.8	35.9
1915-19	29.1	3.8	8.9	41.8
1910-14	25.7	3.1	8.4	37.2

* Source: U. S. Dept. of Agriculture and War Food Administration, Interbureau Committee on Post-War Programs.

† Data compiled by calendar years.

‡ Including rayon, silk, flax, jute, hemp, and various hard fibers. Includes small quantities of mohair 1935-1943, but mohair is included with wool for 1910-1934.

TABLE 19.9. SPOT COTTON, WOOL, SILK, AND RAYON PRICES *
Raw Cotton, Scoured Raw Wool, Raw Silk, and Rayon Filament
Yarn (per Pound)

Year	Cotton	Wool	Silk	Rayon †
1945	\$0.226	\$1.18	....	\$0.55
1944	0.212	1.19	....	0.55
1943	0.206	1.18	....	0.55
1942	0.193	1.19	....	0.55
1941	0.139	1.09	\$2.94	0.54
1940	0.102	0.96	2.77	0.53
1939	0.093	0.83	2.71	0.52
1938	0.089	0.70	1.69	0.52
1937	0.118	1.02	1.86	0.62
1936	0.124	0.92	1.76	0.57
1935	0.121	0.75	1.63	0.57
1934	0.124	0.82	1.29	0.59
1933	0.085	0.67	1.61	0.61
1932	0.063	0.47	1.56	0.66
1931	0.083	0.63	2.40	0.75
1930	0.132	0.76	3.41	1.06
1929	0.186	0.96	4.93	1.25
1928	0.195	1.16	5.07	1.50
1927	0.174	1.10	5.44	1.49
1926	0.175	1.16	6.19	1.82
1925	0.234	1.39	6.57	2.05
1924	0.287	1.41	6.25	2.11
1923	0.293	1.41	8.65	2.80
1922	0.212	1.25	7.65	2.80
1921	0.151	0.85	6.57	2.69
1920	0.339	1.66	9.08	4.60
1919	0.325	1.74	9.64	4.77
1918	0.318	1.84	6.96	4.40
1917	0.235	1.59	6.27	3.86
1916	0.145	0.87	5.54	3.11
1915	0.102	0.71	3.32	2.08
1914	0.121	0.61	3.69	1.95
1913	0.128	0.57	3.64	1.85
1912	0.115	0.64	3.45	1.85

* Source: *Rayon Organon*.

† 150-denier viscose rayon.

TABLE 19.10. ANNUAL UNITED STATES RAYON PRODUCTION * †
(Millions of Pounds)

Year	Viscose, Cupra and Nitro ‡ filament yarn	Acetate § filament yarn	Total filament yarn	Total staple fiber §	Grand total, rayon
1945	449	175	624	168	792
1944	383	172	555	169	724
1943	338	163	501	162	663
1942	310	169	479	154	633
1941	287	164	451	122	573
1940	257	133	390	81	471
1939	231	98	329	51	380
1938	182	76	258	30	288
1937	238	83	321	20	341
1936	215	63	278	12	290
1935	202	56	258	4	262
1934	170	38	208	2	210
1933	172	41	213	2	215
1932	117	18	135	1	136
1931	135	16	151	1	152
1930	117	10	127	0.4	128
1929	113	8	121	0.5	122
1928	91	6	97	0.2	97
1927	71	5	76	..	76
1926	60	3	63	..	63
1925	49	2	51	..	51
1924	36	0.1	36	..	36
1923	35	0.1	35	..	35
1922	24	0.1	24	..	24
1921	15	0.1	15	..	15
1920	10	0.1	10	..	10

* Source: Textile Economics Bureau, Inc., *Rayon Organon*.

† Above data include only rayon filament yarn and rayon staple fiber; other primary rayon products such as rayon producers' waste, bands and strips, and monofil are not included. All data shown, however, are on a 100% basis.

‡ Since 1934 the data in this column include only the production of filament yarn by the viscose and cuprammonium processes, nitrocellulose yarn production having been discontinued in 1934. The viscose and cuprammonium data have been combined to avoid disclosure of individual company operations.

§ Acetate yarn and staple fiber production are partially estimated; acetate staple fiber production is combined here with viscose staple fiber production.

TABLE 19.11. PRODUCTION OF RAYON STAPLE FIBER IN THE
UNITED STATES *
(Millions of Pounds)

<i>Year</i>	<i>Viscose</i>	<i>Acetate</i>	<i>Total</i>
1945	129.1	39.3	168.4
1944	128.4	40.3	168.7
1943	129.6	32.4	162.0
1942	127.6	25.7	153.3
1941	105.3	16.7	122.0
1940	70.6	10.5	81.1
1939	45.3	6.0	51.3
1938	26.4	3.5	29.9
1937	16.6	3.6	20.2
1936	9.8	2.5	12.3
1935	4.3	0.3	4.6
1934	2.2	..	2.2
1933	2.1	..	2.1
1932	1.1	..	1.1
1931	0.9	..	0.9
1930	0.4	..	0.4
1929	0.5	..	0.5
1928	0.2	..	0.2

* Source: *Rayon Organon*, February 1946.

TABLE 19.12. WORLD PRODUCTION OF FOUR TEXTILE FIBERS *
(Millions of Pounds)

<i>Year</i>	<i>Cotton</i>	<i>Wool</i>	<i>Silk</i>	<i>Rayon</i>	<i>Total</i>
1944	12,350	2,300	30	2,156	16,836
1943	12,800	2,450	50	2,633	17,933
1942	12,750	2,490	80	2,750	18,070
1941	12,500	2,540	115	2,759	17,914
1940	13,700	2,500	127	2,463	18,790
1939	13,100	2,460	123	2,300	17,983
1938	13,200	2,340	123	1,951	17,614
1937	17,600	2,280	121	1,824	21,825
1936	14,700	2,230	119	1,322	18,371
1935	12,600	2,160	121	1,081	15,962
1934	11,000	2,120	125	824	14,069
1933	12,500	2,170	122	691	15,483
1932	11,200	2,200	116	535	14,051
1931	12,700	2,230	126	508	15,564
1930	12,100	2,210	130	457	14,897
1929	12,600	2,250	134	441	15,425
1928	12,400	2,250	129	361	15,140
1927	11,200	2,170	118	295	13,783
1926	13,400	2,140	111	212	15,863
1925	12,800	2,010	104	185	15,099
1924	11,500	1,920	97	138	13,655
1923	9,125	1,800	88	103	11,116
1922	8,825	1,820	82	77	10,804
1921	7,250	1,830	77	48	9,205

* Sources: *Cotton*: New York Cotton Exchange Service, converted to pounds on the basis of 478 lbs. per bale. *Wool*: Grease-equivalent figures from *The Wool Situation*, U. S. Bureau of Agricultural Economics, converted to the scoured basis shown at 60% of grease. *Silk*: 1921 to 1937, *League of Nations Statistical Year Book*; 1938 to 1940, Commodity Exchange, Inc.; 1941 to 1944 data are estimated. Baleage data are converted at 132½ lbs. per bale. *Rayon*: Filament yarn plus staple fiber; *Rayon Organon*, December 1945.

TABLE 19.13. WORLD PRODUCTION OF FOUR TEXTILE FIBERS *
(Percentage of Total)

<i>Year</i>	<i>Cotton</i>	<i>Wool</i>	<i>Silk</i>	<i>Rayon</i>
1944	73	14	..	13
1943	71	14	..	15
1942	71	14	..	15
1941	70	14	1	15
1940	73	13	1	13
1939	73	13	1	13
1938	75	13	1	11
1937	81	10	1	8
1936	80	12	1	7
1935	79	13	1	7
1934	78	15	1	6
1933	81	14	1	4
1932	80	15	1	4
1931	82	14	1	3
1930	81	15	1	3
1929	82	14	1	3
1928	82	15	1	2
1927	81	16	1	2
1926	84	14	1	1
1925	85	13	1	1
1924	84	14	1	1
1923	82	16	1	1
1922	82	17	1	..
1921	79	20	1	..

* Source: *Rayon Organon*, December 1945.

TABLE 19.14. WORLD PRODUCTION BY COUNTRIES AND AREAS * +
RAYON YARN AND STAPLE FIBER
(Millions of Pounds)

Year	United States	Great Britain	France	Italy	Russia	Germany	Other Europe	Japan	Other countries	World
1945	792	...	...	...	..	...	...	...	..	1,700 \$
1944	724	140	58	300	25	650	196	111	53	2,157
1943	663	130	123	350	24	920	202	178	43	2,633
1942	693	125	125	440	22	920	179	260	46	2,750
1941	573	150	105	450	20	800	150	405	46	2,759
1940	471	170	59	370	19	725	104	503	42	2,463
1939	380	180	72	310	17	655	102	549	35	2,300
1938	288	138	73	268	16	465	91	585	27	1,951
1937	342	152	78	263	15	344	96	509	25	1,824
1936	290	143	66	196	14	194	79	321	19	1,322
1935	262	122	66	153	13	136	74	238	17	1,081
1934	211	91	62	107	12	101	70	158	13	824
1933	216	82	59	84	9	72	61	99	9	691
1932	136	71	52	72	6	61	58	70	9	535
1931	152	54	44	76	4	66	57	48	7	508
1930	128	48	51	67	1	63	58	37	5	457
1929	122	55	42	73	1	61	58	26	4	441
1928	97	52	30	57	+	49	54	17	4	361
1927	76	39	24	54	+	41	47	10	3	295
1926	63	26	19	37	+	25	36	5	2	212
1925	51	30	14	31	+	26	29	3	1	185
1924	36	25	13	18	+	23	22	1	..	138
1923	35	17	8	11	..	14	17	1	..	103
1922	24	14	7	7	..	11	13	1	..	77
1921	15	9	4	3	..	8	2	+	..	48
1920	10	6	3	2	..	5	1	+	..	33

TABLE 19.14. WORLD PRODUCTION BY COUNTRIES AND AREAS *†—Continued
RAYON STAPLE FIBER
(Millions of Pounds)

Year	United States	Great Britain	France	Italy	Germany	Other Europe	Japan	Other Countries	World
1945	168	..	...	...	...	...	...	...	700 §
1944	169	60	29	150	500	125	83	1	1,117
1943	162	55	65	250	700	113	122	...	1,467
1942	153	50	65	310	700	83	174	2	1,537
1941	122	60	45	310	600	57	297	1	1,492
1940	81	60	17	250	550	34	286	2	1,280
1939	51	60	15	191	500	22	309	1	1,149
1938	30	32	11	167	330	14	375	1	960
1937	20	33	11	156	219	7	174	1	821
1936	12	26	7	110	95	2	46	1	299
1935	5	9	5	68	38	1	14	...	140
1934	2	2	4	22	16	1	5	...	52
1933	2	2	2	11	9	1	1	...	28
1932	1	1	2	9	3	†	1	...	17
1931	1	1	1	1	4	...	...	...	8
1930	†	1	...	1	4	...	...	...	6
1929	1	2	..	2	2	...	...	...	7

* Source Rayon Organon.

† In view of the comparatively small amount of trade in rayon, the above data on production provide a reasonably satisfactory indication of mill consumption.

‡ Less than 500,000 lbs.

§ Estimated.

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NYLON (POLYAMIDE)

PRODUCTION OF POLYAMIDES

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MANUFACTURE OF CELLULOSE ACETATE FILAMENTS BY THE DRY
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MANUFACTURE OF SAPONIFIED CELLULOSE ACETATE FILAMENTS

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Eastman Kodak Co.

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